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A REVIEW OF THE ALABAMA DEPARTMENT OF TRANSPORTATION'S POLICIES AND PROCEDURES FOR LIFE-CYCLE COST ANALYSIS FOR PAVEMENT TYPE SELECTION

Final Report

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October 2013

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Abbreviations

AASHTO .... American Association of State and Highway Transportation Officials
AC .... Asphalt Concrete
ACPA .... American Concrete Pavement Association
ADT .... Average Daily Traffic
AADT .... Average Annual Daily Traffic
ALDOT .... Alabama Department of Transportation
CPI .... Consumer Price Index
CPR .... Concrete Pavement Restoration
DOT .... Department of Transportation
ESAL .... Equivalent Single Axle Load
FHWA .... Federal Highway Administration
GAO .... Government Accounting Office
HMA .... Hot-Mix Asphalt
IRI .... International Roughness Index
LCCA .... Life-Cycle Cost Analysis
LTPP .... Long-Term Pavement Performance
MM .... Million
MEPDG .... Mechanistic-Empirical Pavement Design Guide
MSIR .... Materials Specific Inflation Rate
NAPA .... National Asphalt Pavement Association
NCAT .... National Center for Asphalt Technology
NCHRP .... National Cooperative Highway Research Program
NHS .... National Highway System
NPV .... Net Present Value
OGFC .... Open-Graded Friction Course
OMB .... Office of Management and Budget
PAC .... Price Adjustment Clause
PMA .... Pavement Management System
PCCP .... Portland Cement Concrete Pavement
PCI .... Pavement Condition Index
pcplph .... passenger cars per lane per hour
SAPA .... State Asphalt Pavement Associations
SHA .... State Highway Agency
SN .... Structural Number
UA .... University of Alabama

Executive Summary

Life-Cycle Cost Analysis (LCCA) is an economic analysis process for assessing the cost-efficiency of competing alternatives based on the Net Present Value (NPV) concept. This analysis is often used to select between asphalt and concrete pavements for highway projects. While the process of calculating the NPV, which is defined as the sum of present values of initial and future costs and returns, is straightforward for each alternative, the challenge is to gather reliable data for the inputs. The Federal Highway Administration (FHWA) guidelines recommend that inputs be based on the best available historical information on pavement performance, state-approved design, construction and maintenance practices, and current information on costs and discount rates.

The Alabama Department of Transportation (ALDOT) has conducted LCCA as part of its pavement type selection process since around 1990. However, questions regarding ALDOT's current LCCA policy were raised by the concrete paving industry when Alabama House Bill 730, which requires an LCCA for each "Major Infrastructure Project," was introduced. Thus, ALDOT tasked the National Center for Asphalt Technology (NCAT) and the University of Alabama to review and make recommendations for updating its LCCA procedure.

This report provides NCAT's review results, case studies and recommendations based on federal guidelines, data provided by ALDOT and other state agencies, and current practices. A summary of significant findings is provided below.

1. LCCA Trigger. The current ALDOT policy generally requires LCCA only for new pavement construction or reconstruction of high traffic roadways, such as interstate highways. This policy has been implemented in the past decades and aligned with the approved design and construction practices in Alabama. During the LCCA review, the concrete paving industry has suggested that LCCA be conducted for each project whose total cost estimate is equal or greater than the arbitrary $3 million threshold. This arbitrary threshold will require ALDOT to conduct LCCA not only on new construction or reconstruction projects but also on rehabilitation projects which primarily consist of milling and overlaying with a thin asphalt surface; however, the concrete paving industry has not presented cost information, performance data, or a validated structural design procedure for a thin concrete alternative that can be used in Alabama. Furthermore, the arbitrary and fixed $3 million threshold proposed by the concrete paving industry would force ALDOT to immediately dedicate additional human and financial resources to a new LCCA program and expand this program over time as inflation erodes the purchasing power of $3 million. Additionally, the concrete industry claims they just want the opportunity to compete on new pavement construction or reconstruction projects. However, in four recent alternate-bid projects, there were no concrete paving bidders for three of the projects. For the one project where concrete contractors submitted bids, the lowest concrete bid was 25% higher than the low-bid asphalt alternate. It would be a waste of ALDOT's time and resources (actually, taxpayers' money) on the extra designs and LCCAs without any added returns on its

investments. Therefore, it is doubtful that requiring LCCAs on additional projects or requiring more alternate bid projects would create any added value for the Department. Thus, NCAT recommends that ALDOT continue its current policy on when to perform an LCCA until further guidelines are provided from the U.S. Government Accounting Office, which is reviewing LCCA practices as required by MAP-21.

2. Performance Periods. ALDOT currently uses the initial and rehabilitation performance periods for asphalt pavements based on a limited survival analysis conducted in 1990. This analysis was based on the performance data collected on pavements that had been built at least a decade earlier. A recent analysis by ALDOT's Pavement Management Office found that the average service life of asphalt overlays is 13.4 years, which is much longer than the rehabilitation performance period used in the current LCCA policy. However, ALDOT does not have reliable data for determining the initial performance period of newly constructed asphalt pavements. Therefore, other sources were sought for information on the initial performance period. The best set of reliable data is the nationally-funded Long-Term Pavement Performance (LTPP) program managed by FHWA. A 2005 study of new HMA pavements in the LTPP database found that based on the International Roughness Index (IRI), the expected service life was 20 years for a low distress threshold as commonly used for interstate highways, and 22 years for moderate distress thresholds typically used for other highways. Other DOTs that have recently examined their Pavement Management System (PMS) data have also noted much longer initial performance periods for asphalt pavements. Florida and Missouri reported initial performance periods of 18 and 19 years, respectively. Thus, NCAT recommends an initial performance period of 19 years and a rehabilitation performance period of 13.5 years for asphalt pavements in LCCA.
3. Analysis Period. The Analysis Period used in LCCA should be long enough to include major rehabilitations for competing alternatives, but not too long as to introduce unnecessary uncertainty. Data on the service lives of concrete pavements were gathered and analyzed to provide a recommendation on the shortest LCCA analysis period. Based on ALDOT data, 134 miles of concrete pavements on Alabama interstate highways have been rubblized or demolished by the "break and seat" method since 1995 because it was no longer feasible to maintain these pavements. The average age of those pavements at the time they were demolished was 32 years. Those pavements were replaced with asphalt pavements. Other states report similar experiences. In addition, 100 miles of the remaining 168 miles of concrete pavements on Alabama's interstate highways have been overlayed with asphalt to improve smoothness, friction, and/or tire-pavement noise. The remaining 68 miles include some recently reconstructed concrete pavements and 13 older projects ranging from 15 to 45 years old. Although the older concrete projects are still in service after 30 years, most are at or beyond FHWA's "acceptable" roughness threshold. Based on this information, NCAT recommends that the Analysis Period be set at 35 years so as to include at least one major rehabilitation for both pavement types.
4. Removal/Demolition Costs and Salvage Value. Based on ALDOT's and other agencies' experiences, concrete pavements eventually must be completely removed or rubblized and replaced, whereas asphalt pavements are rehabilitated indefinitely by milling and

overlaying the upper layers. To account for this difference, the LCCA should include removal or rubblization costs for concrete pavements, the salvage value for the portion of the asphalt pavement that remains intact from the initial construction, and the salvage value of the remaining service life for the last rehabilitation. This report provides the procedures and examples for including demolition or rubblization costs and salvage values in LCCA.

5. Initial and Future Pavement Costs. Cost data for the initial construction, maintenance, rehabilitation, and demolition activities should be unit prices from recent bid records of projects. For asphalt pavements, ALDOT has good records and a good process for using representative cost data based on weighted average winning bids from the past twelve months of ALDOT lettings. Because of limited data for concrete paving projects in Alabama, historical data may need to include projects from two or more years. When that is the case, the historical bid prices should be adjusted to current costs by applying an inflation factor. Cost data from other states and federal sources may be helpful for observing trends, but should be viewed with extreme caution since each state has unique materials and construction specifications that impact the bid prices. NCAT also strongly recommends that ALDOT include concrete rehabilitation activities besides joint sealing. Ignoring other rehabilitation activities, such as slab replacement, diamond grinding, under-sealing, and asphalt overlays that are commonly used to maintain concrete pavements is an unfair advantage to concrete pavements in LCCA.
6. Other Costs to the Agency. When the pavement material choice affects other significant aspects of the project, such as adjusting bridges, slopes, and drainage structures, and results in very different maintenance of traffic schedule, those differential costs must be included in the LCCA. NCAT does not recommend including engineering and construction management costs for rehabilitation activities until further analysis can establish fair values for such costs from ALDOT projects.
7. Material-Specific Inflation Rate. The concrete industry has used rising prices of asphalt binder in recent years to imply that inflation rates for asphalt pavement materials far exceed that of concrete paving materials. However, actual cost data for asphalt and concrete mixtures in Alabama and other states show that unit prices for both materials have increased by similar rates in the past decade. The material-specific inflation rate adjustment invented by advocates of the concrete paving industry is not appropriate for use in LCCA primarily because it assumes that the factors driving specific material price changes in the past will continue throughout the analysis period. Increased domestic production of crude oil and natural gas through improved extraction technologies, continued development of other energy sources, and changing attitudes of US consumers and industries to be more energy conscious will shift the fundamental drivers of crude oil prices. Continued increases in recycled material contents, as proven on the NCAT Test Track and numerous field projects, will also diminish future demands on raw materials and reduce the cost of asphalt pavements. Moreover, new environmental regulations on cement plants to curtail mercury and other pollutants, and a pending ruling by EPA and/or congressional act to define fly ash as a non-hazardous or hazardous material are likely to significantly impact cement supply and costs. Because it is impossible to reliably predict general inflation or commodity prices

even for a few years, much less over many decades, use of the material-specific inflation rate ploy is not recognized as valid practice by the economics profession and is not endorsed in any government literature.

8. Discount Rate. FHWA recommends using a *real* discount rate that is "consistent with OMB Circular A-94 real interest rates," and "discount rates should reflect historical trends over long periods of time." Given that the current real discount rate published by OMB is at an all-time low of 2.0%, but historically tends to follow a cyclical pattern, the rate is expected to rise again as the economy strengthens. NCAT recommends that ALDOT use a 10-year rolling average of the OMB real discount rate in LCCA.
9. User Costs. User Costs are extra expenses incurred by the driving public as they travel through or are detoured around a project with lane closures. Although FHWA provides a straightforward process for estimating User Costs, the process is sensitive to estimates of future traffic and vehicle operating costs. NCAT recommends that User Costs only be considered when the Net Present Value of the LCCA alternatives are within 10% of each other or when the project is likely to result in long lane closures during the Analysis Period.

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

1. INTRODUCTION

1.1. Background

Life-Cycle Cost Analysis (LCCA) is a structured process for conducting an economic analysis of two or more competing investment alternatives that takes into account all anticipated costs over the life of an investment. It is considered a fair and balanced process to identify the best long-term value among competing alternative investments. The Alabama Department of Transportation (ALDOT) has used LCCA as a key part of its decision making process for whether to use asphalt or concrete as the primary material for pavement construction on certain projects since around 1990.

Alabama House Bill (HB) 730 *(1)* was introduced by State Representative McCutcheon (R-Huntsville) on April 19, 2012. The Bill was referred to the House Committee on Transportation, Utilities and Infrastructure and subsequently postponed indefinitely on May 9, 2012. The Bill requires a Life-Cycle Cost Analysis (LCCA) to be performed by ALDOT for each "Major Infrastructure Project" prior to the Legislature appropriating funding. According to the Bill, a "Major Infrastructure Project" is defined as any project, be it "Highway, transit, rail, high-speed rail, airport, seaport, public housing, energy, water, bridge, and military construction projects for which the state's total cost estimate, including the cost of materials, is not less than three million dollars."

Although HB 730 was not moved out of committee in the 2012 legislative year, it raised questions about ALDOT's current LCCA policies. In July of 2012, ALDOT tasked the National Center for Asphalt Technology (NCAT) and the University of Alabama (UA) to review ALDOT's current LCCA procedure and make recommendations on when and how to conduct LCCAs. Preliminary recommendations from NCAT and UA were presented in a series of short position papers and discussed in front of the Project Advisory Committee on December 7, 2012.

1.2. Objective

The objective of this report is to review ALDOT's current policies and procedure and provide ALDOT with recommendations of how to best calculate the Life-Cycle Costs of asphalt and concrete pavements. These recommendations are based on federal guidelines, data provided by ALDOT and other state agencies and current, state-of-practice techniques.

1.3. Scope

This report examines all factors considered before and during an LCCA. Recommendations are given where appropriate for revisions to ALDOT's current policy on LCCA. The recommendations for input parameters are applicable to both asphalt and concrete pavement types.

1.4. Report Organization

This report is presented in six sections. Section 1 is this brief introduction. Section 2 discusses the historical approaches to LCCA and details the NCAT research approach. It also describes the basic inputs required to conduct an LCCA, defines commonly used terms, and discusses various software platforms used to conduct an LCCA. Section 3 examines when an LCCA should be performed. LCCA inputs, their effects, and NCAT's policy recommendations are discussed in detail in Section 4. Section 5 provides case-studies of six recent ALDOT projects to demonstrate the impacts and sensitivity of the recommendations from both NCAT and the UA Team. A concise summary of NCAT's and UA's recommendations is presented in Section 6.

2. OVERVIEW OF LIFE CYCLE COST ANALYSIS

2.1. Primer on LCCA

The objective of an LCCA is to evaluate the overall long-term economic efficiency between competing alternative investment options. The Net Present Value (NPV) concept is applied to compare the costs over the life spans of the alternatives. The NPVs of the 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. In addition, relevant User Costs can be considered. A risk analysis can be performed to assess the sensitivity of the results to the analysis inputs. The results can be used to select the most cost-effective option.

Figure 2.1 shows potential expenditures for each pavement alternative that should be considered in the LCCA. Equation 2.1 is used to calculate the NPV of all the expenditures for each alternative.

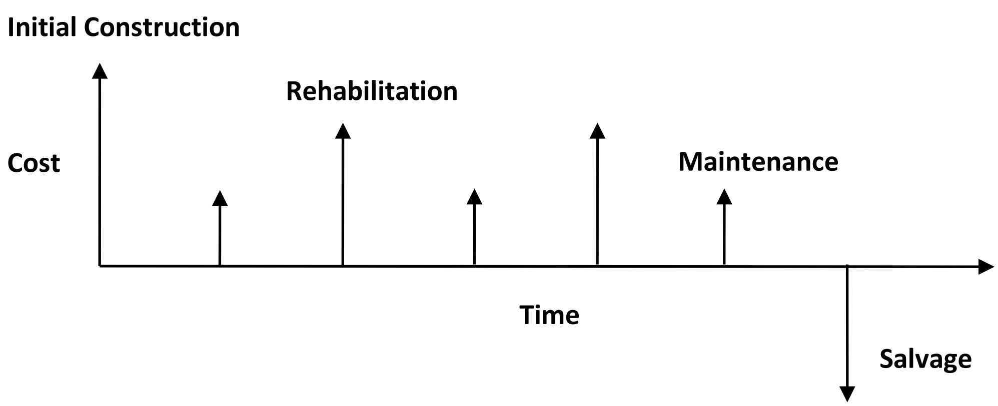

Figure 2.1 Stream of Expenditures for a Paving Project

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

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, year

The potential cost components included in the NPV determination include:

- Agency costs for materials, labor and traffic control
- User costs due to delay and for vehicle operating

In the course of a pavement's life cycle, several maintenance operations and rehabilitation efforts will be performed. Using historical data, the year and nature of the maintenance and rehabilitation activities can be predicted. Figure 2.2 shows the model life-cycles of two competing alternatives under consideration in an LCCA.

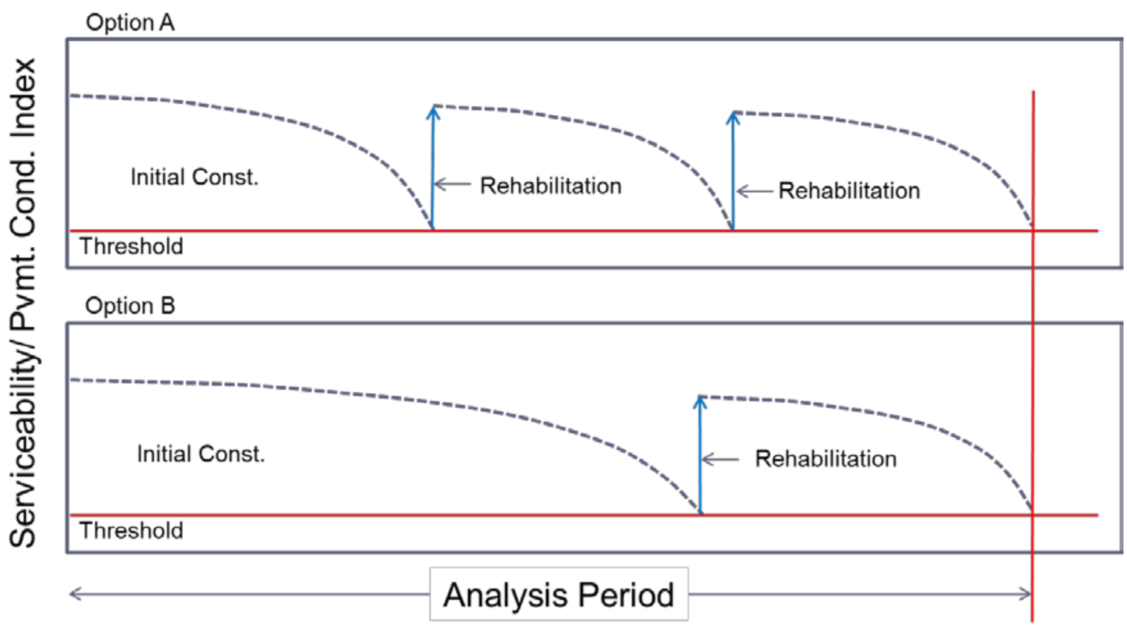

Figure 2.2 Ideal Life Cycle Diagrams of Two Hypothetical Pavement Alternates

Each rehabilitation cost can be estimated from current cost data *(2)*. Effects of inflation are removed 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. If the pavement has value remaining at the end of the Analysis Period, a Salvage Value can be credited to the present value of the alternative.

2.1.1. Use of LCCA for Pavement Type Selection

The concept of LCCA for pavement type selection has been used, in some form, since the 1950s *(3).* The original approach was the consideration of benefit-cost ratios. Over time, the preferred method has been to calculate the NPV by discounting future costs to account for the time-value growth of money. State Highway Agencies' practices varied widely until a 1993 push 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 *(4).* 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 *(5).*

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 *(2)*. This Bulletin is widely cited as the primary reference for using LCCA in pavement type selection.

2.1.2. Background Information

According to the 2011 ALDOT Annual Report there are currently 10,625 centerline miles of asphalt pavement in the state highway system *(6)*. This includes overlays of concrete pavements. There are 165 miles of concrete pavement, and this number has been declining. Fourteen percent of the highway miles are classified as Interstate Highways, 31% are part of the non-interstate NHS, and 55% are state highways. In 2011, 682.7 miles were resurfaced and 63.4 miles were rehabilitated or reconstructed.

2.2. LCCA Definitions

2.2.1. Analysis Period

The Analysis Period is the time horizon over which future costs are evaluated in the LCCA. Common wisdom is that the Analysis Period should be long enough to include at least one major rehabilitation for each design alternative. If one alternative will require reconstruction, the Analysis Period should be selected to include demolition costs at the end of that alternative's life span.

2.2.2. Net Present Value

The Net Present Value (sometimes also called Net Present Worth) is the discounted monetary value of all expected net benefits (i.e., benefits minus costs). The NPV is calculated using Equation 2.1 (p. 3).

2.2.3. Discount Rate

The Discount Rate accounts for the time-value growth of money. A cost or return in the future is worth less to the owner today than in the year the activity occurs. In essence, the Discount Rate is an interest rate in reverse. Discount Rates can be reflected in *Real* or *Nominal* terms. Real discount rates do not account for the effect of inflation and are more widely used than Nominal rates in LCCA.

2.2.4. Performance Periods

Common LCCA practices use two types of performance periods. The first type is the Initial Performance Period which represents the average time span in years for a newly constructed pavement (or reconstructed pavement) to reach the agency's criteria (or threshold) for rehabilitation. Asphalt and concrete pavements are generally considered to have different Initial Performance Periods. The second type of performance period commonly used in LCCA is the Rehabilitation Performance Period which is the time span for the rehabilitated pavement to again reach the agency's criteria for next rehabilitation. FHWA guidelines recommend that agencies determine performance periods for different pavement strategies through analysis of Pavement Management System data and historical experience. Service Life is a synonymous term to Performance Period.

2.2.5. Pavement Preservation, Maintenance, Rehabilitation, and Reconstruction

There are numerous terms used in the industry to categorize activities used to maintain pavements. In the context of LCCA, it is important to distinguish the types of activities and when they are likely to occur in the life of a pavement. FHWA provided definitions and examples in a memorandum on September 12, 2005 (*7*). The authors have edited the definitions to eliminate circular references and revised the list of examples for consistency.

Pavement Preservation

Definition: 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

Definition: "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)." (*8*)

Preventive maintenance is typically applied to pavements in good condition having significant remaining service life. As a major component of pavement preservation, preventive maintenance is a strategy of extending the service life by applying cost-effective treatments to the surface or near-surface of structurally sound pavements.

> Example preventive maintenance treatments for asphalt pavements include: asphalt crack sealing, chip seals, micro-surfacing, and thin HMA overlays.
>
> Example preventive maintenance treatments for concrete pavements include: concrete joint sealing, spall repairs, repair of isolated corner breaks, and diamond grinding.

Pavement Rehabilitation

Definition: "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." (*9*)

"Rehabilitation projects extend the life of existing pavement structures either by restoring existing structural capacity through the elimination of age-related, environmental cracking of the pavement surface or by increasing pavement thickness to strengthen existing pavement sections to accommodate existing or projected traffic loading conditions."

> Example rehabilitation activities for asphalt pavements include: structural HMA overlays with or without milling.
>
> Examples rehabilitation activities for concrete pavements include: full-depth slab removal and replacement, under-sealing, dowel-bar retrofit, HMA overlays, and bonded concrete overlays (insufficient data exists on performance periods for bonded concrete overlays for this method to be adequately considered in LCCA).

Routine Maintenance

Definition: "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." *(9)*

“Routine maintenance consists of day-to-day activities that generally performed by maintenance personnel to maintain and preserve the condition of the highway system at a satisfactory level of service… Routine Maintenance activities are often “in-house” or agency-performed and are not normally eligible for Federal-aid funding” and typically not included in LCCA.

> Example routine maintenance activities for asphalt pavements include: maintenance of pavement markings, crack filling, pothole patching, and isolated overlays.
>
> Example routine maintenance activities for concrete pavements include: isolated spall repair, temporary repair of punch-outs or blow-ups, temporary patches with HMA.

Reconstruction

Pavement reconstruction is 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.

> Asphalt pavements are rarely entirely reconstructed. Exceptions may include localized pavement failures due to weak supporting layers, or rebuilt sections to change the pavement’s geometric alignment.
>
> Example reconstruction activities for concrete pavements include: rubblizing the existing concrete pavement into a base layer and building a new asphalt pavement on top (common in rural highways); “break & seat” the existing concrete pavement (a technology largely replaced by rubblization) followed by an asphalt overlay; unbounded concrete overlays (in essence, this means burying the existing concrete pavement and building an entirely new concrete pavement, typically over a new asphalt concrete base); and removing the existing concrete pavement and replacing with a new concrete or asphalt pavement (common in urban projects where it is not feasible to alter other structures to accommodate a significant change in roadway elevation necessary with rubblization or unbounded concrete overlays).

2.2.6. Agency Costs

Costs included in LCCA are all costs associated with the pavement alternative that are incurred by the agency during the analysis period and can be expressed in monetary terms. These include initial construction costs, subsequent rehabilitation design and construction costs, maintenance costs, traffic control costs during construction, maintenance, and rehabilitation work, and demolition or removal costs or residual value of the pavement structure at the end of the analysis period. Only agency costs that differ significantly for the competing alternatives need be included in the LCCA. Engineering and construction management costs, for example, may be excluded if they are similar for the alternatives. Rehabilitation and maintenance costs used in LCCA should not only consider the types and quantities of materials and work items, but also the traffic control plan (detours, lane closures, work hours, etc.) necessary for each alternative *(10).*

2.2.7. Salvage Value

Salvage Value is the expected worth of the investment at the end of the Analysis Period. This value can reflect the literal material worth (Residual Value) or the remaining service life of the pavement structure and last rehabilitation.

2.2.8. User Costs

User Costs are costs incurred by the traveling public and commerce affected by the project during maintenance, rehabilitation, or reconstruction activities. These costs account for time-delays experienced by users and include the costs of operating vehicles for a longer period of time and the missed opportunity costs incurred by users because of delays from moving through work zones or detours. User Costs can be can be extremely large for high-traffic-volume projects that have lane or road closures for long periods of time.

2.3. Analysis Methods and Programs

2.3.1. 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 on page 3) used for LCCA is an example of a deterministic solution. Using a Deterministic Approach to LCCA ignores variability 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 use a Deterministic Approach in LCCA.

2.3.2. Probabilistic Approach

Since most LCCA inputs are estimates or projections, there is some uncertainty with those values and therefore with the LCCA outcome. Table 2.1 summarizes the LCCA inputs that have intrinsic uncertainty.

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 either a normal or a triangular-shaped probability distribution. More 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 2.1.

Table 2.1 LCCA Input Variability *(2)*

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

A 2008 South Carolina DOT Survey *(11)*, as shown in Figure 2.1, found very few states using the Probabilistic Approach.

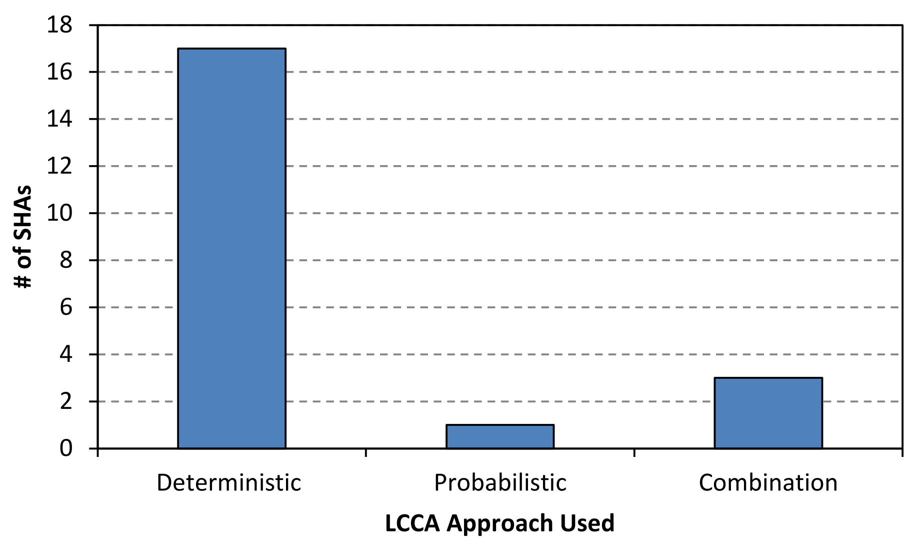

Figure 2.1 LCCA Approaches used by State Highway Agencies *(11)*

2.3.3. Software

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.

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 (*12*). The Asphalt Pavement Alliance released a more user-friendly software platform simply called *LCCA* that can also compute User Costs and utilize a Probabilistic Approach (*13*). *LCCA* has an extensive help file that facilitates navigation through complicated User Cost procedures. *LCCA* is also free for download. Both *RealCost* and *LCCA* yield the same results and follow the guidelines of the 1998 FHWA Technical Interim Bulletin *Life-Cycle Cost Analysis in Pavement Design.* ALDOT currently uses the AASHTO's DARWin *Pavement Design and Analysis System* for LCCA. This program cannot employ a Probabilistic Approach or consider User Costs and is no longer supported by AASHTO. Figure 2.2 shows the software programs used by SHAs based on a 2008 South Carolina DOT survey *(11).*

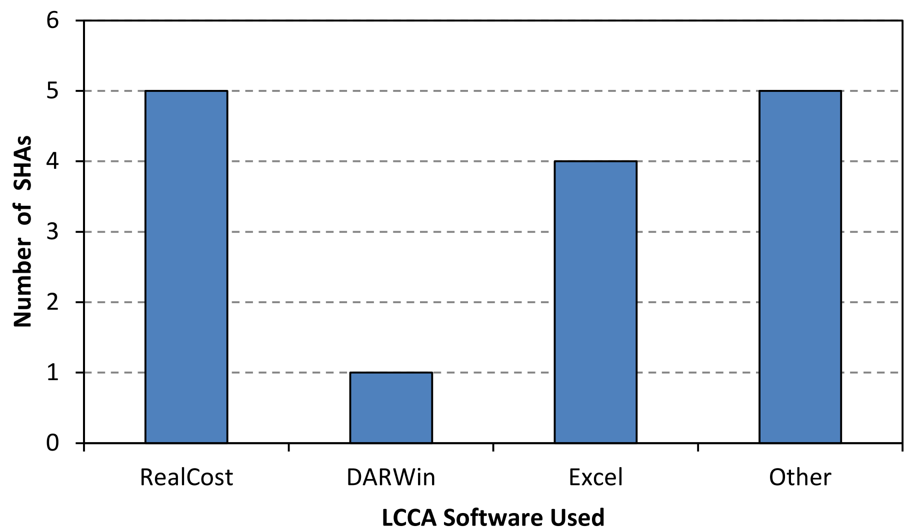

Figure 2.2 LCCA Software Used Among Various SHAs *(11)*

2.4. Gathering Information

Guidance and information for this report were obtained from a variety of credible sources. The primary sources for LCCA policy guidance were from the most recent FHWA technical bulletins and reports. Primary data for pavement performance, construction costs, and materials costs were obtained from ALDOT. Other sources of information were included where ALDOT data were limited.

2.4.1. *Current Policy*

ALDOT's current LCCA policies were last updated in 2003 *(14).* ALDOT uses the following inputs:

- Analysis Period of 28 years
- Discount Rate of 4%
- Initial Performance Period of 12 years for asphalt pavements
- Rehabilitation Performance Period of 8 years for asphalt pavements
- Initial Performance Period of 20 years for concrete pavements
- Rehabilitation Period of 8 years for concrete pavements
- No Salvage Value considered
- No User Costs considered
- Deterministic Approach

ALDOT requires LCCA when the structural number (SN) for the asphalt pavement design is greater than or equal to six inches. If an LCCA has been performed on similar projects on the same route or in the same geological formation within the last five years, then performing a new LCCA is unnecessary.

2.4.2. *Surveys*

Four national surveys on LCCA practices are referenced in this report. The Mississippi DOT commissioned a survey of 21 SHAs in 2003 *(15).* The South Carolina DOT conducted a survey in 2005 and updated it in 2008 *(11).* The State Asphalt Pavement Association's (SAPAs) 2010 survey includes responses from 46 states *(16).* The Wisconsin DOT commissioned a survey regarding pavement performance, maintenance, and rehabilitation activities performed in an LCCA *(17).*

3. WHEN TO CONDUCT AN LCCA

3.1. Introduction

Life-Cycle Cost Analysis can be a useful engineering tool in pavement type selection. However, LCCA is not warranted for all projects, and in certain situations the cost and time of performing an LCCA can be an unnecessary burden on the Department. This section examines ALDOT's current policy, proposed changes in Alabama HB 730, and makes a recommendation based up research being conducted by the Government Accountability Office (GAO) as directed by MAP-21.

3.2. Current ALDOT's LCCA Practice

The current ALDOT policy (*18*) requires an LCCA when the structural number (SN) of the asphalt pavement design is 6.00 or greater. An LCCA is not required if:

- The project is less than four center-lane miles in length.
- An LCCA was performed on the same route within ten miles from the project under consideration, or the two projects are located in the same geological formation and the two projects have approximately the same traffic and commercial vehicles (±20%).

However, an LCCA is required if:

- The LCCA done on the previous project is more than five years old.
- There is a change in the number of one-directional through lanes on the mainline roadway.
- The required SN for the project under consideration exceeds the required SN for the previous project by more than 20%.
- The difference in costs between the two lowest alternatives was less than 10%.
- The Materials and Tests Engineer determines that an LCCA is necessary

Furthermore, all projects involving the reconstruction of concrete require an LCCA.

3.3. Alabama House Bill 730

Alabama House Bill 730 (*1*) was introduced by State Representative McCutcheon (R-Huntsville) on April 19, 2012. The Bill was referred to the House Committee on Transportation, Utilities and Infrastructure and subsequently postponed indefinitely on May 9, 2012. The Bill requires an LCCA to be performed by ALDOT for each "Major Infrastructure Project" prior to the Legislature appropriating funding. According to the Bill, a "Major Infrastructure Project" is defined as any project, be it "Highway, transit, rail, high-speed rail, airport, seaport, public housing, energy, water, bridge, and military construction projects for which the state's total cost estimate, including the cost of materials, is not less than three million dollars."

3.4. Federal Recommendations and Legislation

The National Highway System Designation Act of 1995 required States to conduct LCCAs on NHS projects costing $25 million or more. This requirement was removed in 1998 by Transportation Equity Act for the 21st Century (TEA-21) (*5*). A proposal to require LCCAs for all highway projects valued at $5million or more was proposed to the US Senate Environment and Public Works Committee as part of the 2012 Moving Ahead for Progress in the 21st Century (MAP-21) but was not put into the final version of the law. MAP-21 required the GAO to work with AASHTO to examine this issue, and this consideration is currently underway (*19*).

As illustrated in Figure 3.1, over the five year period from 2007 to 2011, between 66.7 and 73.9% of all ALDOT projects had winning bids below $3 million. Conversely, between approximately ¼ and ⅓ of all ALDOT projects exceeded the $3 million threshold, including on average 18% of all pavement rehabilitation projects on existing roadways and 89% of all new pavement construction projects.

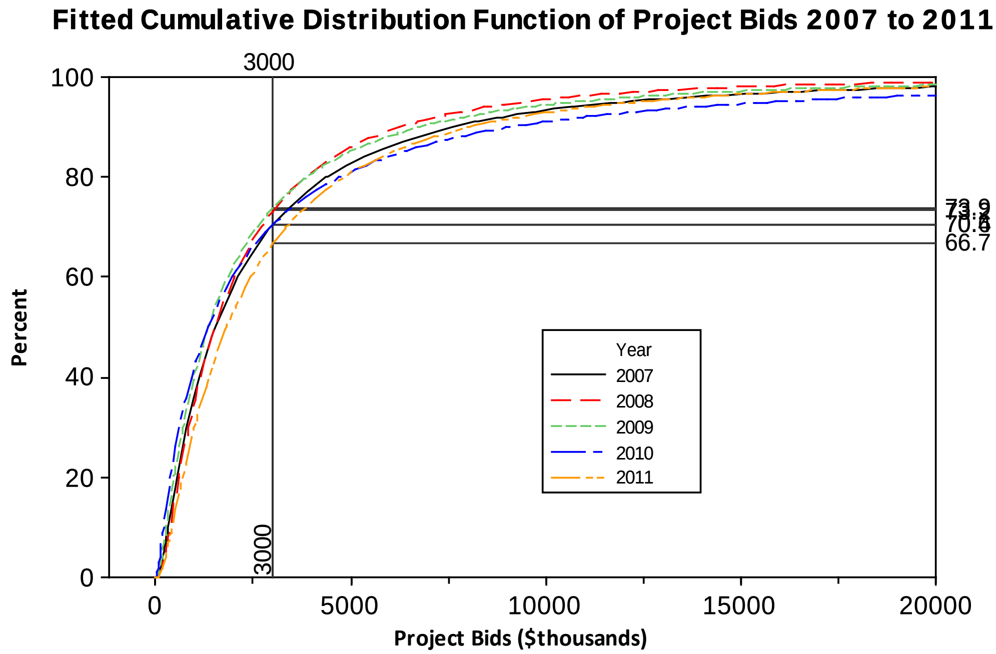

Figure 3.1 ALDOT Infrastructure Projects Requiring LCCA at Various Triggers (2007-2011) (*20*)

Using the proposed $3-million trigger, ALDOT would have performed an LCCA on approximately four times as many projects in each of the last five years. A recent survey of ALDOT Divisions determined that current life-cycle cost analyses typically takes two days and in some cases more than one week (*21*). In essence, a new full-time analyst/engineer position would be needed immediately to satisfy the requirements of such a policy. Assuming that ALDOT implements some recommendations from this NCAT report or the one from the UA team, LCCAs will likely become more complex in the future and the additional staffing burden for LCCA analyses would easily double.

3.5. Potential Issues and Detrimental Impacts of the Bill Requirement

Potential Problem 1: For many ALDOT projects, the pavement is not the major cost item.

For example, bridge replacement projects may only include a small amount of paving for approaches and tie-ins. If the intent is to require LCCA for pavement type selection, then it should only be applied to projects where the paving is the primary cost item.

Potential Problem 2: The concrete paving industry has not provided supporting information for thin concrete pavement technologies that are competitive for pavement rehabilitation projects in an initial cost or a life-cycle cost basis.

Using recent ALDOT data, each year there are 20 to 30 pavement rehabilitation projects that exceed $3 million. Rehabilitation of asphalt pavements typically consists of a 2-3 inch mill and overlay. In some cases, asphalt overlays are also used for concrete pavement rehabilitation. Advocates of the concrete paving industry claim that thin concrete overlay projects have been built in other states, however they have not provided any data on costs, validated design procedures to determine appropriate overlay thicknesses, or long-term performance reports that are needed to determine inputs for LCCA. Anecdotal references are not sufficient for a state's pavement type selection policy.

<u>Potential Problem 3: The requirement does not take into account the time-value of money that is the basic principle behind the LCCA.</u>

Figure 3.2 shows the present worth of $3-million in the future (i.e., 5 to 30 years from now). The calculations were done using the nominal discount rates that include the inflation premium published in the OMB Circular A-94 Appendix C revised December 2011 (*22*). Figure 3.3 shows the estimated numbers of LCCAs that would be conducted each year in the future if the $3-million requirement was implemented. The estimated numbers were determined based on the present worth of $3 million shown in Figure 3.3 and the database of paving projects for fiscal years 2007 through 2011. It clearly shows the detrimental effect of the requirement on the ALDOT operation in the future. If the requirement was not updated, ALDOT would be required by the Bill to perform LCCAs on over 85 projects each year (over 50% of all paving projects) in 20 years from now. Future LCCAs are likely to require additional analyst/engineering time as more detailed data is needed and program complexity increases (such as using probabilistic methods and including user costs and salvage value). Using a fixed dollar-figure threshold in a policy for LCCA would become an increasing burden on the Department.

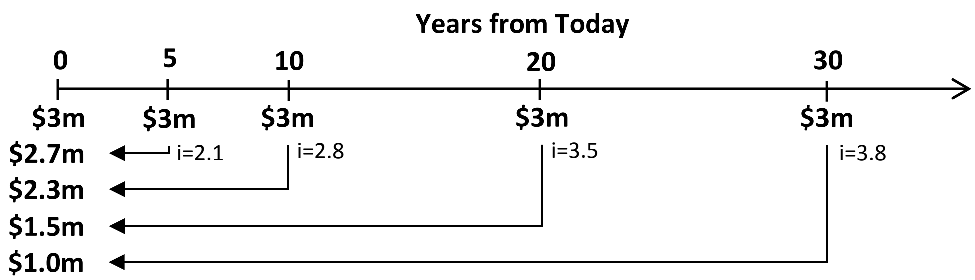

Figure 3.2 Present Value of $3 million in the Future

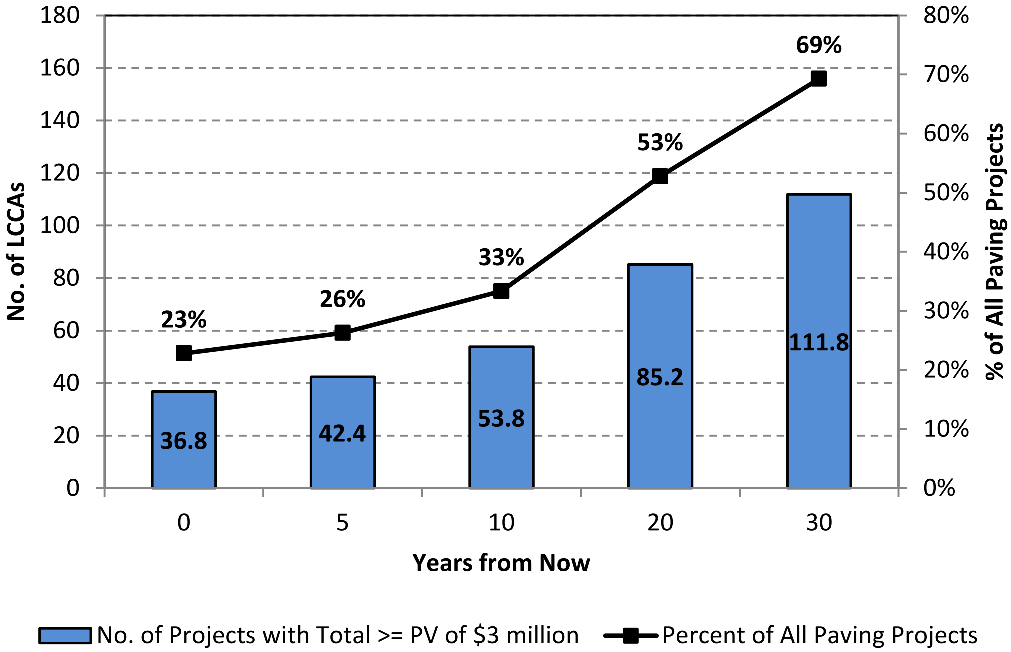

Figure 3.3 Estimated Number of LCCAs Conducted Each Year in the Future

<u>Potential Problem 4: For those projects in which LCCA was conducted, how many projects could concrete paving products be used and would concrete paving contractors bid on?</u>

Based on the current ALDOT construction specifications and the current list of approved products, there are limited concrete paving products that can be used in Alabama. If the $3-million requirement was implemented, as shown in Figure 3.3 (above), an LCCA would be conducted for 37 paving projects of which 28 projects are resurfacing each year. The first question is which approved concrete paving products can be used in the resurfacing projects and have they been used successful in Alabama.

In addition, the concrete paving industry wants to have the opportunity to compete on additional new construction or reconstruction projects. However, there were no concrete paving bidders for three out of four alternate-bid projects conducted in the recent past. For the one project where concrete contractors submitted bids, the lowest concrete bid was 25% higher than the low-bid asphalt alternate. It would be a waste of ALDOT's time and resources (actually, taxpayers' money) on the extra designs and LCCAs without any added returns on its investments.

<u>Potential Problem 4: What could be done in the LCCA if the expenditure of a future rehabilitation option also exceeds $3 million?</u>

For example, if it was determined that the future expenditure for the first Rehabilitation (see Figure 2.1 on p. 3) exceeded the $3 million threshold, a second analysis would be required within the first analysis, essentially resulting in an open-loop trap.

3.6. Costs of Performing an LCCA

A recent survey of ALDOT Divisions determined the calculation of an LCCA to take at least two days and in some cases more than one week (*21*). Nine LCCAs have been calculated by ALDOT in the last five years. If the $3 million trigger had been in place, approximately 37 LCCAs would have been required. As a result of this study and a similar one from the UA Team, future LCCA may become much more complex requiring additional time for gathering appropriate input data and analysis. Thus the time to complete future LCCAs could easily be double.

3.7. Survey of State Agencies

A 2008 survey commissioned by the South Carolina Department of Transportation (SCDOT) (*11*) found that the Trigger for LCCA varied amongst the states.

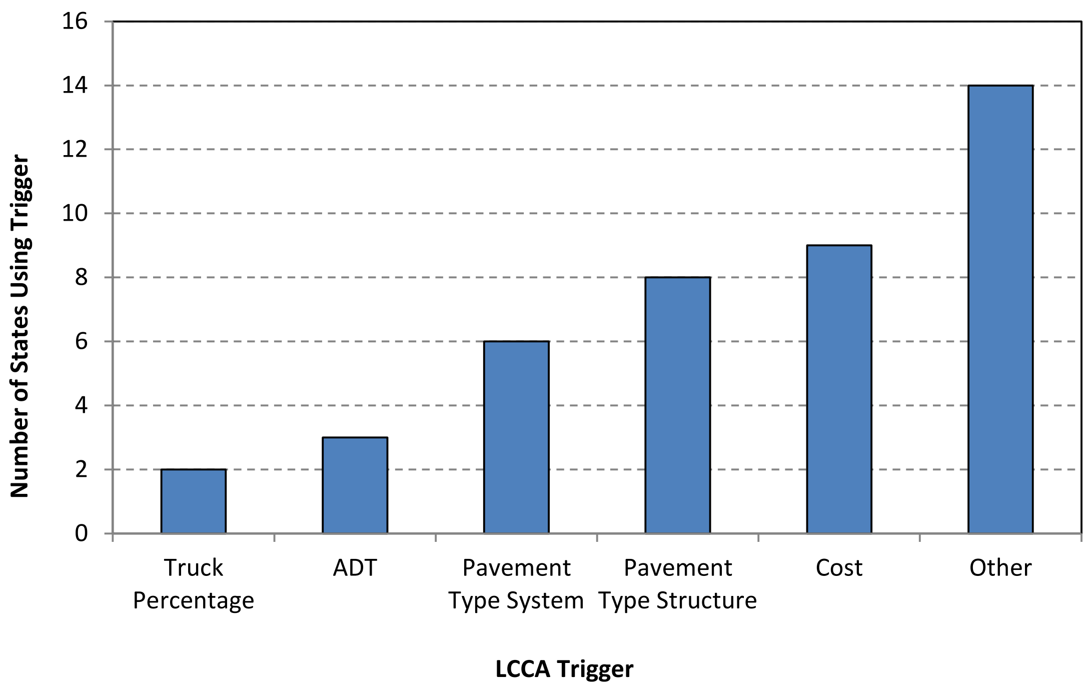

Figure 3.4 Summary of 2008 SCDOT LCCA Survey—Triggers for LCCA (*11*)

3.8. Recommendations

With the potential issues and detrimental impacts of the $3-million LCCA requirement, it is recommended that this trigger not be adopted. The requirement fails to take into account the time-value of money that is the basic principle behind the LCCA and would create an increasing burden on ALDOT operations and project delays in the future. If the $3-million threshold is implemented, the LCCA will be an unnecessary exercise that will create no added value to resurfacing projects due to the fact that, aside from a few recent anecdotal projects, there is insufficient information for thin-overlay concrete paving products needed for LCCAs. In addition, the $3-million requirement will also make the LCCA more complicated than necessary when the cost of rehabilitation exceeds the $3-million threshold. Since MAP-21 requires the GAO to work with AASHTO to examine LCCA practices, it is anticipated that more rational guidelines for when LCCAs should be conducted will be recommended (*23*). Hence, it is recommended that ALDOT's current policy for triggering LCCA continue until the GAO-AASHTO analysis is completed and their recommendation can be considered.

4. LCCA INPUTS AND RECOMMENDATIONS

4.1. Analysis Period

4.1.1. Introduction

The Analysis Period is one of the most important parameters in the determination of a pavement's Life-Cycle Cost. It is the length of time for which competing strategies must be evaluated during an LCCA. This period should be long enough to include all of the major costs each alternative incurs during its life-span. However, since the Analysis Period is essentially the time span over which an agency must predict future performance and expenditures, it should be set as short as possible to minimize uncertainty.

4.1.2. Current ALDOT Policy

Current ALDOT policy sets the Analysis Period for LCCA as 28 years. However, as shown in Table 4.1, the activity schedule does not include any costs or benefits after year 20. For all effective purposes, ALDOT currently uses a 20-year Analysis Period.

Table 4.1 Current ALDOT LCCA Schedule

Year	Asphalt Pavements	Concrete Pavement
0	Initial Construction	Initial Construction
12	Mill and Replace Wearing Surface	-
20	Mill and Replace Wearing Surface and Upper Binder Layer	Clean and Seal Joints, Re-Striping

4.1.3. Other Guidance

The FHWA provided guidance on choosing the Analysis Period in *An Interim Policy Statement on LCCA* published in the July 11, 1994 (*24*). 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 (2)*. 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 (*25*)." This "good practice" standard was the final recommendation made in accordance with the National Highway System Designation Act of 1995 (*26*).

The American Concrete Pavement Association (ACPA) recommends an Analysis Period of "45-50+" years (*27*). 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."

4.1.4. Time to Terminal Serviceability

The Analysis Period should be long enough to consider reconstruction of concrete pavements. ALDOT, like many states, has faced the difficult challenges associated with concrete pavements that have reached their terminal serviceability. Since 1995, 134 miles of concrete pavement on 24 interstate projects in Alabama have been demolished by rubblization or "break & seat" because it was no longer feasible to maintain the concrete pavements (*28*). The average age of the interstate concrete pavements at the time they were demolished was 32 years. Those pavements were replaced with asphalt.

Other highway agencies have had a similar experience. From 1998 to 2010, 161 miles of concrete on Louisiana interstates were rubblized and another 18 miles are planned (*29*). 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 *(30)*. The average age of those rubblized concrete pavements in Florida was 28.2 years. Kentucky DOT reported that the average age of concrete pavements when they were destroyed and overlayed with asphalt using the "break & seat" method was 25.5 years (*31*).

One significant limitation with many DOT's pavement management database is the inability to properly identify the original pavement type. Since a common rehabilitation practice is to overlay concrete pavements with asphalt, in these cases, it is common for the pavement type to thereafter be mislabeled. Some experts in the pavement management community refer to these as "composite" pavements. The performance lives of these "composite" pavements would then be skewed due to reflection cracking and roughness resulting from movements of the underlying concrete.

Of the remaining concrete pavements on Alabama's interstate highways (approximately 168 miles), there are 31 miles reported as "composite" pavements, and another 69 miles reported as "thin composite" pavements (*32*). Thin composites are concrete pavements with a very thin asphalt overlay (typically less than one inch) with an open-graded friction course or "paver-laid surface seal" to improve smoothness, friction, and/or tire-pavement noise. The remaining 68 miles of concrete pavements on Alabama's interstate highway include a few new concrete pavements and 13 older projects ranging from 15 to 45 years old. Although a few of those older concrete projects are still in service after 30 years, most are at or beyond the International Roughness Index (IRI) threshold for "acceptable" roughness. These concrete pavements older than 30 years old have an average IRI 168 inches/mile with a range of 80 to 247 inches/mile. FHWA established the IRI benchmark for "acceptable" ride quality at 170 inches/mile or less, and 95 inches/mile or less as a "good" ride quality. Only one of the "over 30" concrete pavements has an IRI in the "good" ride quality. For comparison, the average IRI for asphalt pavements is 63 inches/mile with 94% in the "good" ride quality *(33).*

As noted in AASHTO's 2009 report *Rough Roads Ahead (34)*, the American public pays twice for poor road conditions - once for higher vehicle operating costs, and the second time for higher costs to restore pavements to good condition.

> "Driving on rough roads accelerates vehicle depreciation, reduces fuel efficiency, and damages tires and suspension. TRIP estimates that for the average driver, rough roads add $335 annually to typical vehicle operating costs. In urban areas with high concentrations of rough roads, extra vehicle operating costs are as high as $746. Generally, larger vehicles have a greater increase in operating costs due to rough roads."

4.1.5. Uncertainty

Selection of the Analysis Period should also consider that a higher level of uncertainty goes along with longer periods of time. The further that projections of the current state of knowledge are made into the future increases the risk that those projections will be wrong. In LCCA, project pavement service lives, construction methods, traffic patterns, user delay costs, and discount rates are all projected into the future. To illustrate the point of increasing uncertainty with longer forecasts, ALDOT traffic data used in the rehabilitation design of 30 interstate pavements from about 20 years ago were analyzed. 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. Since some errors were positive and others were negative, a simple average of the errors has little meaning. The distribution of the errors is more telling. Table 4.2 shows a summary of the statistics for the traffic projection analysis. It can be seen that the standard deviation of the error increased as the traffic projection went further into the future. This trend would continue if the predictions went out to 30, 40, 50, or more years. At 40 years, for example, the span of the 90% Confidence Interval on AADT would increase to 110%, meaning that the traffic projection could be off by more than 100%.

Table 4.2 Results of Traffic Projection Analysis

Analysis of Traffic Forecasting Accuracy	Forecast Years	Avg. Error (% of AADT)	Standard Deviation of Error (% of AADT)	Span of 90% Confidence Interval (% of AADT)
30 Alabama Interstate Projects Time span: 1986 to 2011	5	8	11	18.1
	10	12	14	23.0
	15	8	18	29.6
	20	-4	24	39.5

Since traffic projections are a fundamental input for pavement design, roadway capacity, and user cost estimates, it is unwise to project any farther into the future than necessary to capture the terminal service life of concrete pavements.

4.1.6. Analysis Periods Used by Other DOTs

The most recent comprehensive survey of LCCA practices by states, 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 10 years indicate slightly different distributions of Analysis Period. Figure 4.1 shows a box-plot diagram of the Analysis Period surveys. 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 cross-hairs sign.

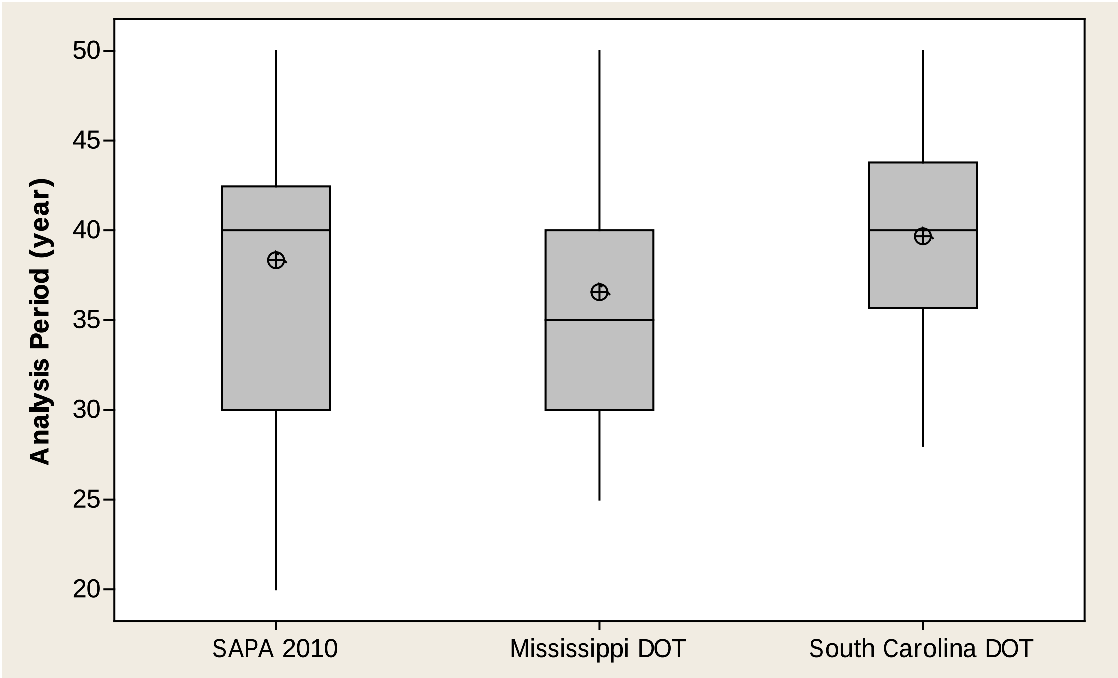

Figure 4.1 LCCA Analysis Periods from Recent Surveys

4.1.7. Recommendation

It is generally agreed that the Analysis Period should be long enough to include at least one major rehabilitation effort for each alternative so that long-term differences in discounted life-cycle costs among the alternatives are included in the analysis. Longer Analysis Periods increase uncertainty in the calculation of each alternative pavement's Net Present Value. Analysis Period should therefore be the minimum length of time required for significant rehabilitation or reconstruction costs. An Analysis Period of 35 years is sufficient to include multiple rehabilitation cycles for asphalt pavements and, as ALDOT records indicate, a high percentage of interstate concrete pavements are either removed from service by in-place demolition or removal, overlayed, or exceed the acceptable roughness standard by age 35.

4.2. Performance Periods

4.2.1. Introduction

ALDOT currently uses a 12-year initial Performance Period and an 8-year Performance Period for subsequent rehabilitations for asphalt pavements in its LCCA. These values were established based on historical performance data in 1989. Advancements have been made in ALDOT's standards for asphalt mixtures, quality assurance, and construction practices over the past 24 years. This section provides new data that support new Performance Periods for asphalt pavements for use in LCCA.

4.2.2. Performance Periods Defined

In the context of LCCA, there are two terms that refer to the performance periods (usually in years) of asphalt and concrete pavements considered in the analysis. First, the Initial Performance Period of a pavement is the length of time from the initial construction until the pavement undergoes the first rehabilitation. Second, the Rehabilitation Performance Period is the time period between two consecutive rehabilitation activities (e.g. asphalt overlays), which is also referred to as the "overlay service life".

Ideally, Performance Periods would be determined based on historical data from the agency's Pavement Management System (PMS) and pavement performance thresholds that trigger the agency's rehabilitation or reconstruction activities. Currently, few agencies possess Pavement Management Systems with sufficient detail to capture the "true" Performance Periods.

4.2.3. Determination of Performance Periods

When ALDOT began to conduct LCCAs in 1990, its Pavement Management System was only five years old, and pavement condition surveys were still being conducted manually except for roughometer data that had to be run at speeds below 30 mph. An initial "survival analysis" of roughometer data collected prior to 1990 provided the statistics for Performance Periods shown in Table 4.3 (*39*).

Table 4.3 Survival Analysis of Pavements Based on Pre-1990 ALDOT Roughometer Data

Pavement Activity	No. of Projects	Performance Period (years)			
		Average	Std. Dev.	Min.	Max.
Bituminous Initial Construction	73	12.1	4.3	3.8	26.4
Bituminous Overlay	33	9.1	4.1	2.2	20.3
Plain Jointed Concrete Initial Const.	26	17.2	4.3	3.9	24.7

These results are reasonably consistent with ALDOT's current LCCA policy for Performance Periods, although apparently somewhat generous for concrete pavements.

However, ALDOT does not currently have sufficient and reliable pavement performance data for determining the initial service lives of newly constructed asphalt pavements (*39*). Therefore, other sources were sought for reliable information on Initial Performance Periods. The best set of reliable data is the nationally-funded Long-Term Pavement Performance (LTPP) program managed by FHWA. A 2005 study by Applied Research Associates examined the performance of new HMA pavements in the LTPP database. Based on the IRI (Table 4.4), the expected service life was 20 years to reach a low distress threshold as used for interstate highways, and 22 years for moderate distress thresholds typically used for other highways (*35*). It is important to note that the distress to first reach its threshold for the first category was rutting, which has been greatly reduced with the use of polymer-modified asphalt binders, SMA, and Superpave mixtures.

Table 4.4 Expected Initial Service Life of Asphalt Pavements Based on LTPP Data (*35*)

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

Additional proof of better performing asphalt pavements is documented with research at the NCAT Test Track. Test sections N3 and N4 built in 2003 to carry 9 million Equivalent Single-Axle Loads (ESALs) of traffic according to ALDOT's current design procedure actually carried 30 million ESALs with no significant distress (*36*), and would have carried many more ESALs if the test sections were not replaced with another experiment. This indicates that the initial Performance Period for asphalt pavements has also dramatically improved with the advancements in asphalt technology.

Other states have examined their performance data and found that their asphalt pavements have longer service lives than previously estimated. Table 4.5 shows the results of Missouri DOT's analysis provided in its 2004 report "*Pavement Design and Type Selection Process, Phase I Report*." (*37*)

Table 4.5 Results of Missouri DOT's Analysis of Overlay Performance Periods (*37*)

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

With regard to the asphalt Rehabilitation Performance Period, a recent analysis by ALDOT's Pavement Management Office of 180 projects awarded between 01/01/11 and 06/30/12 found that the average service life of the prior overlays was 13.4 years (*39*), which is a substantial improvement over the Rehabilitation Performance Period of 9.1 years shown in Table 4.3. However, the current PMS database does not provide sufficient detail to sort projects based on whether the original underlying pavement was concrete or if the overlay surface used an Open-Graded Friction Course (OGFC). Furthermore, since the most significant changes in asphalt pavement specifications, such as Stone Matrix Asphalt, Superpave, polymer-modified binders, and material remixing devices, have been implemented within the 12 years, the benefits of those changes are not evident in the recent analysis.

The Florida DOT has also found that their asphalt pavement performance has steadily improved over the past decade. Figure 4.2 shows that the percentages of the state's lane miles that are deficient with regard to rutting, ride, and cracking have declined over the past 10 years, resulting in an average of 18 years between rehabilitation activities for their asphalt pavements (*30*).

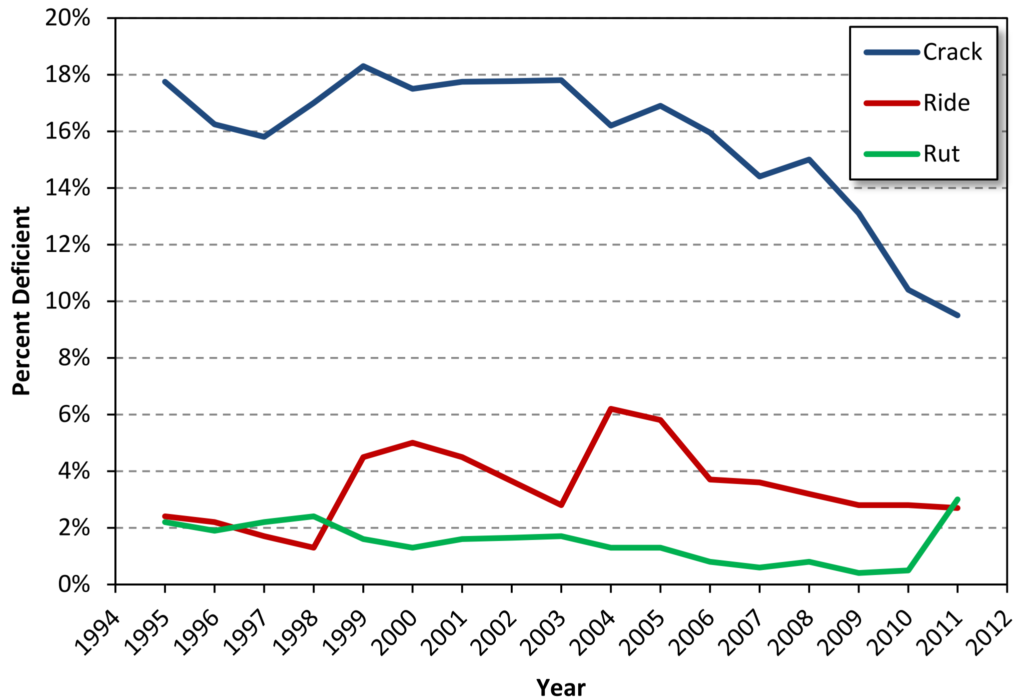

Figure 4.2 Declining Percentages of Deficient Lane Miles in Florida DOT's Highway System

On the national level, FHWA funded a study by Applied Research Associates Inc. that analyzed the performance trends of asphalt overlay test sections in the LTPP database *(35)*. These overlays ranged in age from 9 to 29 years with diverse traffic and environmental conditions and different pavement structures. The report summarized the average service lives of the overlays for six categories of pavement distress as shown in Table 4.6. Based on this data the service life of overlays would be determined by transverse cracking. However, it should be noted that transverse cracking (i.e., thermal cracking) is not a distress common in Alabama. It is also important to note that this study was based on LTPP data through February 1997, and therefore, the overlays included in the analysis also predate the advancements made in asphalt materials and construction during the last several decades.

Table 4.6 Expected Service Life of Asphalt Overlays Based on 1997 LTPP Database

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

A 2010 survey by the State Asphalt Pavement Associations found the average Initial Performance Period for asphalt pavements to be 15.6 years and the average Rehabilitation Performance Period to be 12.25

years. This information is shown in Table 4.7. Most states have used Performance Periods based either on old data, like ALDOT, or on the "experience" of pavement experts.

Table 4.7 Performance Periods Surveyed by State Asphalt Pavement Associations

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

*Inferred rehab. Performance Period is the same as initial Performance Period.

The 2008 SCDOT study *Life Cycle Cost Analysis for Pavement Type Selection* (11) also surveyed other state agencies. Figure 4.3 shows the results of the South Carolina survey. According to this survey, the average Initial Performance Period for asphalt pavements used for LCCA is 16.1 years.

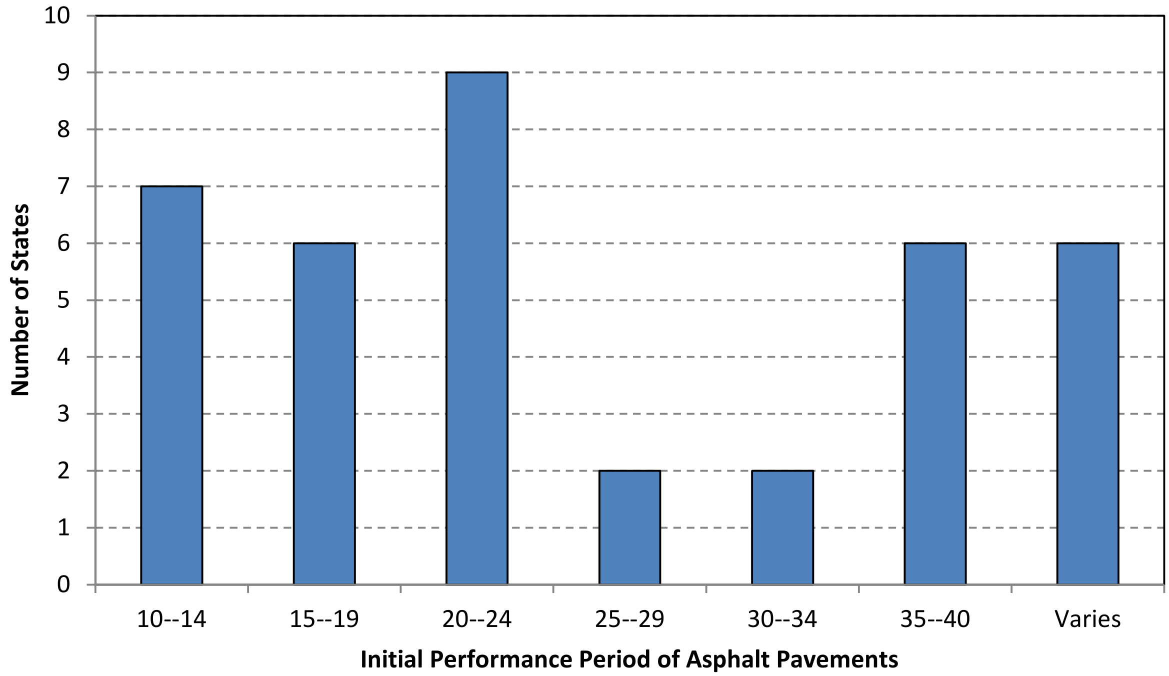

Figure 4.3 Initial Performance Periods of Asphalt Pavements Based on SCDOT Survey (*11*)

4.2.4. Recommendations

The current ALDOT Performance Periods of 12 years and 8 years for initial construction and overlays, respectively, is based on data from more than two decades ago and does not account for the improvements in pavement durability achieved by the utilization of new asphalt specifications implemented by the Department. Several recent studies based on historical pavement performance data indicate much longer Performance Periods for asphalt pavements, as summarized in Table 4.8.

Table 4.8 Summary of Performance Periods Determined based on Historical Performance Data

Recent Analyses	Performance Period (years)			
	Interstate and Urban Freeways (Low Distress Tolerance Level)		US Highway and State Routes (Moderate Distress Tolerance Level)	
	Initial Const.	Rehabilitation	Initial Const.	Rehabilitation
ALDOT		13.4		13.4
MO DOT	18.9	13.2-14.0	19.3-20.7	10.1-12.4
FDOT		18		18
ARA's Analysis of LTTP Data based on IRI	20	13	22	18.5

Based on the above information, the following performance periods are recommended for LCCAs in Alabama:

- The initial Performance Period is 19 years for high traffic roadways (interstate and urban freeways) and 21 years for other pavements.
- The rehabilitation or overlay Performance Period is 13.5 years for all roadways.

Further refinement of the above recommendations should be conducted as follows:

- For the initial Performance Period for high traffic roadways, it is recommended to investigate the performance of 11 rubblized pavement sections constructed in the 1990s listed in Tables 3.1 and 3.2 on page 31 of a 2004 research report by Timm (*38*).
- For the rehabilitation Performance Period, the PMS data collected on pavement sections constructed over the original underlying concrete pavements and on OGFC sections should be separated before the analysis is conducted. It is anticipated that the overlay service lives on the underlying concrete and asphalt pavements will be different and that use of OGFC will be limited in the future unless it is warranted for safety purposes.
- The recommended values should be reviewed at least every four to five years to make sure they do not again fall behind continuous advancements made in asphalt specifications and construction methods. ALDOT's Pavement Management System also should be reviewed to ensure that it is capable of providing information necessary to quantify the benefits associated with new pavement technologies.

4.3. Cost Data

4.3.1. Introduction

An essential part of LCCA part is gathering appropriate and *current* cost data for the construction, maintenance, and other costs relevant to the alternatives under consideration. Cost data for the initial construction, maintenance, rehabilitation, and demolition activities should be unit prices from recent bid records of projects.

4.3.2. Cost Data for Construction, Rehabilitation and Maintenance Activities

For asphalt pavements, ALDOT has good records and a good process for using representative cost data in LCCA. However, only a few new concrete pavements have been built in Alabama in recent years, so there is very little cost information available. Table 4.9 lists a few of the key bid items for the two most recent concrete projects. Note that the bid prices for removing concrete pavement for these two projects were quite different, which may have been due to significant differences in quantities for this item on the projects. However, bid prices for new concrete pavements of similar thickness were the same, despite very different construction operations for these two projects. For the I-59 project, each roadway direction was closed for reconstruction, whereas for the I-65 project, traffic was shifted to maintain multiple open lanes during reconstruction. These unit cost data would not be reliable for other thicknesses. Data from neighboring states, such as shown in Table 4.10, may also be very limited because of relatively few concrete paving projects. It is also unknown how materials and construction specifications in other states may affect their bid prices. For example, the 12" thick concrete pavement bid prices from Florida and Georgia are considerably higher than for Alabama.

Table 4.9 Winning Bid Prices for Recent ALDOT Concrete Paving Projects (*40*)

Project	Bid Item	Bid Price
I-59 Etowah Co. Hinkle Contracting	Removing Conc. Pvmt	$9.00/sy
	Plain Conc. Pvmt. 11"	$38.25/sy
	Plain Conc. Pvmt. 13.5"	$48.00/sy
	Grinding Conc. Pvmt.	$5.25/sy
I-65 Hoover McCarthy Imp.	Removing Conc. Pvmt.	$4.40/sy
	Plain Conc. Pvmt. 12"	$45.00/sy
	Plain Conc. Pvmt. 14"	$48.00/sy

Table 4.10 Average Winning Bid Prices for Concrete Pavements in Florida (*41*) and Georgia (*42*)

Agency and Time Frame	Concrete Pavement	Avg. Bid Price
FDOT (6/2011 to 6/2012)	Plain Conc. Pvmt., 9"	$63.00/sy
	Plain Conc. Pvmt., 10"	$55.53/sy
	Plain Conc. Pvmt., 11"	$68.28/sy
	Plain Conc. Pvmt., 12"	$75.32/sy
	Reinforced Conc. Pvmt., 12"	$192.06/sy
GDOT (2011)	JCPC Class 3, 12"	$63.61/sy

Construction cost data for concrete pavements may have to rely on other sources. Oman Systems Inc. has a proprietary search engine for historical DOT bid tabulation data (BidTabs Professional) from all state DOTs except New Jersey, Alaska, and Hawaii *(43)*. FHWA's National Highway Construction Cost Index (NHCCI) (http://www.fhwa.dot.gov/policyinformation/nhcci.cfm) uses a formula called the Fisher Index to calculate a general indicator for construction price changes based on Oman System's data *(44)*. However, NCAT was unable to find specific data on the NHCCI website for concrete paving or concrete maintenance activity bid items.

Table 4.11 shows a summary of ALDOT historical bid price information for several concrete pavement maintenance activities from Jan. 1, 2000 through April 30, 2012 *(40)*. Comparison of the Lowest Average Bid Price and Highest Bid Price shows a very wide range for each bid item. The wide ranges are likely due to variations in quantities and time among the projects. The Weighted Average Bid Price was calculated to normalize the Average Bid Prices with respect to the bid quantity for each respective project. The data were not analyzed with respect to price trends over time.

NCAT recommends that the historical cost data be reduced to only the most recent year or two, provided that there are four or five projects in the reduced data set. The Weighted Average Bid Price for the items should be used in the LCCA unless the quantity of the item is relatively small.

Table 4.11 Summary of Concrete Pavement Maintenance Bid Prices from ALDOT

Concrete Maintenance & Repair	No. of Proj.s	Lowest Avg. Bid		Highest Avg. Bid		Weighted Avg. Bid Price
		Unit Price	Qnty.	Unit Price	Qnty.	
Removal of Conc. Pvmt. Slab	28	$15.26/sy	2,238	$232.69/sy	192	$70.99/sy
Conc. Pvmt. Replacement Slab	22	$365.73/sy	622	$1074.43/sy	56	$529.99/cy
Grinding Conc. Pvmt.	18	$1.80/sy	695,458	$27.00/sy	670	$2.62/sy
Undersealing Conc. Pvmt.	11	$3.27/lb.	158,040	$8.29/lb.	68,955	$3.90/lb.
Break & Seat Conc. Pvmt.	7	$0.49/sy	70,022	$3.61/sy	2,600	$1.05/sy
Rubblize CRCP	5	$2.32/sy	12,185	$3.58/sy	152,450	$3.31/sy
Rubblize Plain Concrete	9	$1.82/sy	43,494	$2.37/sy	21,080	$1.89/sy
Clean & Seal Type I Joints	13	$1.16/lf	292,160	$5.82/lf	1,140	$1.50/lf
Clean & Seal Type I Cracks	9	$1.62/sy	4,411	$3.67/lf	500	$2.15/lf
Clean & Seal Type II Joints	25	$0.75/lf	1,036,066	$6.67/lf	400	$1.70/lf
Clean & Seal Type II Cracks	15	$0.97/lf	1,000	$6.02/lf	2,000	$1.55/lf

A review of recent LCCAs conducted by ALDOT reveals that the only concrete pavement maintenance activity included in those analyses was cleaning and sealing joints. Clearly other maintenance activities as shown above are conducted and must be included in future LCCAs.

4.3.3. Other Agency Costs

In FHWA's Interim Technical Bulletin on LCCA (2), it states that the analysis "need only consider differential costs between alternatives." Project costs that are common to both alternative pavement types, such as silt fence, replacing guardrail and drainage structures, seeding, etc., will cancel out and may be excluded from LCCA calculations. Most agencies also exclude the DOT's engineering and contract management costs from LCCA since those costs are also be expected to be similar regardless of the pavement type. The UA team proposed that engineering and project management costs of rehabilitation activities be included in LCCA since the rehabilitation activities are inherently different for the pavement types. However, at this time, ALDOT does not track its engineering and contract management costs on a project by project basis, therefore the only way to estimate those costs is to use a rule of thumb that such costs are five to ten percent of the total project costs. Before such costs are added, further study should be conducted to determine what an appropriate percentage is and how much of that cost should be attributed to the pavement rehabilitation versus other activities such as roadside safety enhancements that are commonly included in the projects.

Furthermore, in some cases, the assumption that engineering and project management costs are similar among alternate pavement types for *initial* construction may not be valid. The case of the concrete pavement reconstruction project on I-59 in Etowah County is a good example. That $47.7-million project required extensive adjustments to drainage systems, signage, slopes, and bridges. An asphalt option (rubblization and overlay) would have had a much smaller roadway elevation change and thus required much less up-front engineering costs and project management effort. The time to complete the project with asphalt would have been a few months compared to over two years for the concrete rebuild. Other costs that are not currently included in ALDOT's current LCCA practices, such as differences in traffic control (e.g. barrier wall and message boards) for alternative pavement types should be included in future LCCA practices.

4.3.4. Recommendations

It is recommended that costs for initial construction and rehabilitation activities be based on weighted average winning bid data from the past twelve months of ALDOT lettings. Because of limited data for concrete paving projects in Alabama, historical data may need to include projects from two or more years. When that is the case, the historical bid prices should be adjusted to current costs by applying an inflation factor. Cost data from other states and federal sources may be helpful for observing trends, but should be viewed with extreme caution since each state has unique materials and construction specifications that impact the bid prices.

When the pavement material choice affects other significant aspects of the project, such as adjusting bridges, slopes, and drainage structures, and results in very different maintenance of traffic schedule, those differential costs must be included in the LCCA.

It is also strongly recommended that ALDOT include concrete rehabilitation activities besides joint sealing. Ignoring other rehabilitation activities, such as slab replacement, diamond grinding, and under-sealing, and asphalt overlays that are commonly used by ALDOT to maintain concrete pavements is an unfair advantage to concrete pavements in LCCA.

It is not recommended including engineering and construction management costs for rehabilitation activities until further analysis can establish fair values for such costs from ALDOT projects.

4.4. Pavement Design

4.4.1. Introduction

ALDOT currently conducts pavement designs using the 1993 AASHTO Guide for Design of Pavement Structures based on the empirical design equations developed from the data collected during the AASHO Road Tests completed over 50 years ago *(45)*. The procedure often results in over-designed and less cost-effective pavements; hence, ALDOT has adopted some modifications *(46, 47)*. However, the long-term solution to designing more cost efficient pavements is to implement the DARWin-ME™ design procedure in the future. This section discusses current ALDOT design practices, potential benefits of the DARWin-ME™ design procedure, and important steps that should be considered before the new procedure is fully implemented.

4.4.2. Current ALDOT Pavement Design Practices

ALDOT currently conducts pavement designs based generally on the 1993 version of the AASHTO Guide for Design of Pavement Structures *(45)*, which was incorporated in the DARWin software. This Design Guide was based on the empirical design equations developed solely from the data collected during the AASHO Road Tests completed over 50 years ago with less than 2 million equivalent single axle loads (ESALs) in Ottawa, Illinois. Thus, the Guide lacks the ability to accurately predict pavement performance in other climates and with much higher traffic volumes monitored today. The Design Guide is also not able to account for the new improvements to construction methods and pavement materials. Hence, the use of the Guide often results in over-designed and less cost effective pavements, especially for those designed to carry high traffic volumes.

To overcome the deficiencies in the 1993 Design Guide, ALDOT has adopted the following modifications to the 1993 Design Guide before a better design procedure is implemented in Alabama:

- For concrete pavement designs, the maximum design thickness is 14 inches *(47).*
- For asphalt pavement designs, ALDOT has recently used the calibrated layer coefficient of 0.54 instead of the standard value of 0.44. The use of the calibrated coefficient helps (1) address the climatic differences between the AASHO Road Test location and Alabama and (2) include more recent materials and construction methods in the design (*46*).

4.4.3. DARWin-ME Design Procedure

The DARWin-ME design methodology was built upon the Mechanistic-Empirical Pavement Design Guide (MEPDG). The DARWin-ME procedure includes two parts—mechanistic and empirical. The mechanistic part includes models to determine pavement responses (i.e., stress, strain and deflection). Then, the pavement responses are used as inputs in distress prediction models, also known as "transfer functions," to predict cumulative pavement distresses over time. Each design is an iterative process, including the following steps:

1. The pavement engineer provides traffic, climate, and material inputs as well as a trial pavement thickness. The engineer also sets the design reliability level and critical criterion for each pavement performance indicator. For the individual inputs, the MEPDG allows three levels based on the philosophy that the level of engineering effort exerted in the pavement design process should be consistent with the relative importance, size, and cost of the project.
2. The pavement engineer then runs the DARWin-ME software, which executes both the mechanistic and empirical parts, to predict pavement performance indicators for the trial

pavement design. These performance indicators include pavement roughness, which is quantified according to the IRI, and other major pavement distresses. For each pavement performance indicator, the user-specified design reliability level set in Step 1 is applied to account for the variability of the corresponding distress prediction model when it was calibrated with the field data.

3. After the DARWin-ME analysis of the trial pavement design is complete, the pavement performance indicators are compared with the corresponding critical criteria set in Step 1. The DARWin-ME allows users to set the critical limits or to use the DARWin-ME recommended limits to evaluate the adequacy of each design. If the predictions do not meet the critical limits, the pavement engineer can revise the trial design and repeat the evaluation. The engineer can revise and repeat the evaluation process until an adequate pavement design is selected.

4.4.4. Potential Benefits of Implementing DARWin-ME™ Design Procedure

The DARWin-ME design methodology allows pavement designers to better characterize traffic, climate and materials inputs for predicting cumulated pavement performance over a specified design life *(48).* If this methodology is properly implemented, it is expected to provide several potential benefits. Because of better characterization of design inputs during the design process, it results in more efficient pavement designs.

The DARWin-ME design concept integrates pavement structural design, mix design, construction, pavement management, and maintenance in the design process. The effect of mix design and construction methodology can be accounted for through the material properties used in the design. Information from the pavement management system can be used to set the critical limit for each pavement performance indicator and calibrate the transfer functions. In addition, the distresses predicted by the DARWin-ME design procedure can be used for future maintenance purposes. This integration will allow pavement engineers to optimize pavement designs and establish maintenance programs that can potentially extend the pavement service lives and reduce the pavement life cycle costs.

4.4.5. DARWin-ME™ Implementation Considerations

With the potential benefits of the DARWin-ME design procedure over the 1993 AASHTO Guide, state highway agencies have considered to implement the DARWin-ME design in the future. Before fully implementing the new procedure for designing asphalt and concrete pavements, agencies are conducting the following important steps *(49, 50)*.

- Preparing an implementation plan that can be used to guide the implementation effort and to measure goals and achievements over time.
- Building libraries for input parameters to which the predicted distresses are sensitive. These include materials, traffic and climate inputs. This information is used not only for future design but also in local calibration of the design procedure.
- Conducting local validation and/or calibration of the nationally-calibrated transfer functions that relate the computed pavement responses and damages to observed pavement distresses. The local calibration is important to quantify the error of each distress prediction because it impacts the design thickness and pavement type selection.
- Training personnel to ensure that the design procedure is conducted properly.

Lessons learned from the MEPDG implementation efforts in Indiana, Missouri and Montana have been documented in a draft report prepared by Von-Quintus and Mallela for FHWA *(51)*.

4.4.6. Importance of Local Validation and Calibration

While the DARWin-ME design procedure includes a more sophisticated design approach to better adapt to various design conditions, it still relies on empirical functions (i.e., transfer functions) to relate pavement responses to measurable pavement distresses. These empirical functions have built-in calibration factors that were "nationally calibrated" based on the data from the Long-Term Pavement Performance (LTTP) program. Thus, it may not be optimized for a specific region or state, and the developers of the MEPDG strongly recommended that the design procedure be locally validated and/or calibrated to account for local materials, construction and climate conditions to take the full advantage of the advanced methodology. Several highways agencies, such as Montana, Missouri, Mississippi, Florida, and Georgia, have sponsored studies to locally calibrate the DARWin-ME design procedure. Based on the pavement performance data collected at the NCAT Pavement Test Track, Timm et al. *(52)* showed that the current DARWin-ME design procedure using the nationally calibrated transfer functions overdesigned asphalt pavements. As shown in Figure 4.4, the current DARWin-ME design procedure greatly over-predicted the amount of rutting measured on the test sections. This error, if not corrected, would result in overdesigned pavements. Therefore, local calibration is needed to optimize the design procedure for local materials, construction and climate conditions, resulting in more cost-efficient pavement designs.

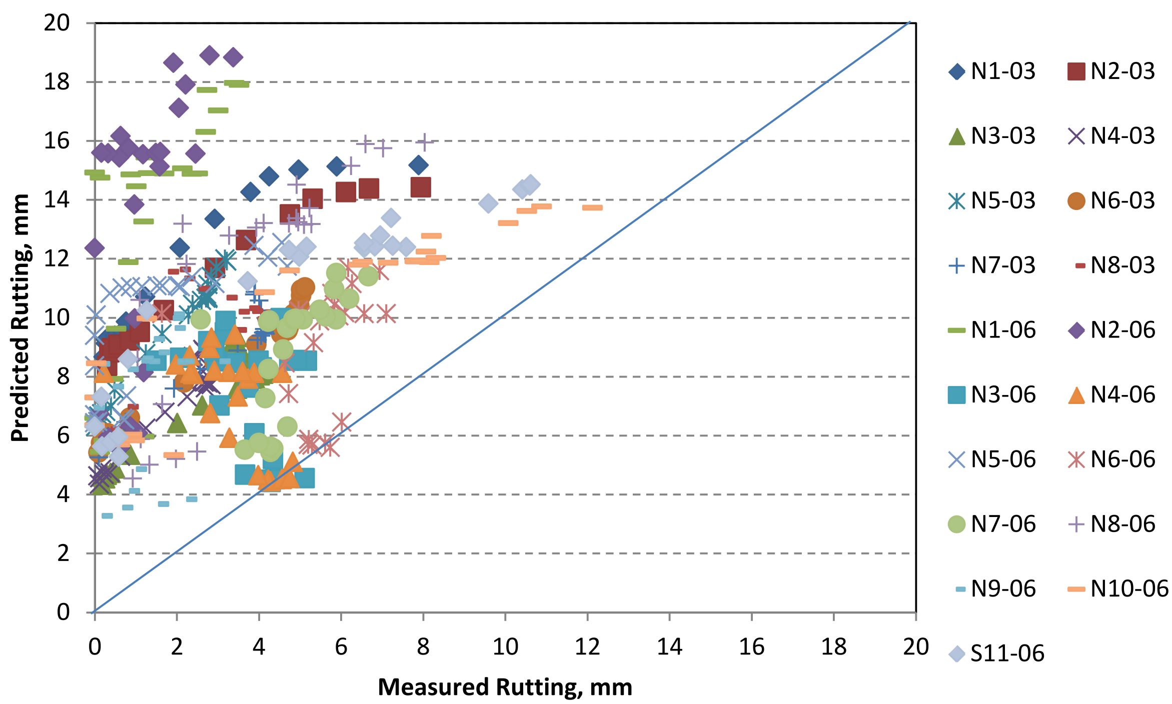

Figure 4.4 Comparison of Measured and Predicted Rutting – National Calibration (52)

4.4.7. Recommendations

With the potential benefits of the DARWin-ME design procedure over the 1993 AASHTO Guide, it is recommended that ALDOT continue toward implementing the DARWin-ME design in the future. In 2010, the Highway Research Center at Auburn University prepared a report for ALDOT on *Guidance for M-E Pavement Design Implementation (53)* which recommended five important steps prior to full implementation of the new design guide:

1. Training of ALDOT personnel and consultants on using the MEPDG program and how to determine the required inputs in the future (Only a preliminary MEPDG workshop has been conducted to date)
2. Build a materials reference library for asphalt mixtures, PCC, and unbound pavement layers
3. Develop a traffic database to include monthly, vehicle class, and axle-load distributions
4. Execute parallel pavement designs using current and MEPDG procedures
5. Local calibration of the MEPDG models to adjust transfer function coefficients

Only a preliminary MEPDG workshop has been conducted to date.

4.5. Discount Rate

4.5.1. Introduction

When performing an LCCA, a discount rate is used to calculate the present value of future costs and returns. This section discusses NCAT's recommendations for using a 10-year moving average of the Office of Management and Budget (OMB) 30-year real interest rate as the discount rate for LCCA.

4.5.2. Discounting and Inflation in LCCA

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. 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 Net Present Value (NPV) of investments, adjusted to constant terms using a discount rate, is shown in Equation 2.1 (p. 3).

4.5.3. Method of Discounting Project Costs to a Point in Time

Several methods exist for the analyst to compute project costs in either "real" (adjusted for the effect of inflation) or "nominal" (values subjected to inflation effects that express future costs in current dollar values) terms. These methods include:

- Conduct in today's dollars and deflate for opportunity value of time.
- Conduct in future dollars (where available, such as in a rent or lease agreement) and deflate for both opportunity value and inflation.
- Inflate today's dollars to reflect "expected future changes in relative prices…where there is a reasonable basis," (22) and deflate for both opportunity value and inflation.

The most common methodology is to conduct the LCCA using constant dollar values and discount with a real discount rate. This computation only requires an analyst to use real costs throughout a project's life cycle. The analyst then applies the Net Present Value formula to remove the effects of the opportunity value of time. Such an approach is the standard practice among government agencies and is recommended by the FHWA. The FHWA's Life-Cycle Cost Analysis Primer directs that "…future costs and benefits of a project should be expressed in constant dollars and then discounted to the present at a discount rate that reflects only the opportunity value of time…."*(54).* Additionally, the 1998 FHWA interim bulletin on LCCA states that "Good practice suggests conducting LCCA using constant dollars and real discount rates *(2)*. This combination eliminates the need to estimate and include an inflation premium for both cost and discount rates."

4.5.4. Selection of a Real Discount Rate

The OMB is tasked with assisting the President with preparing the Federal budget. Since 1979, the OMB has been recommending a real discount rate. This rate represents an estimate of the average rate of return on private investment, before taxes and after inflation *(55)*. The FHWA has recommended using real discount rates that are "consistent with OMB Circular A-94 real interest rates," but these recommendations also advise, "discount rates should reflect historical trends over long periods of time *(2)*." Most states 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. 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 *(22).* 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 4.5 provides the annual 30-year interest rates published for each year from 1979 to 2012.

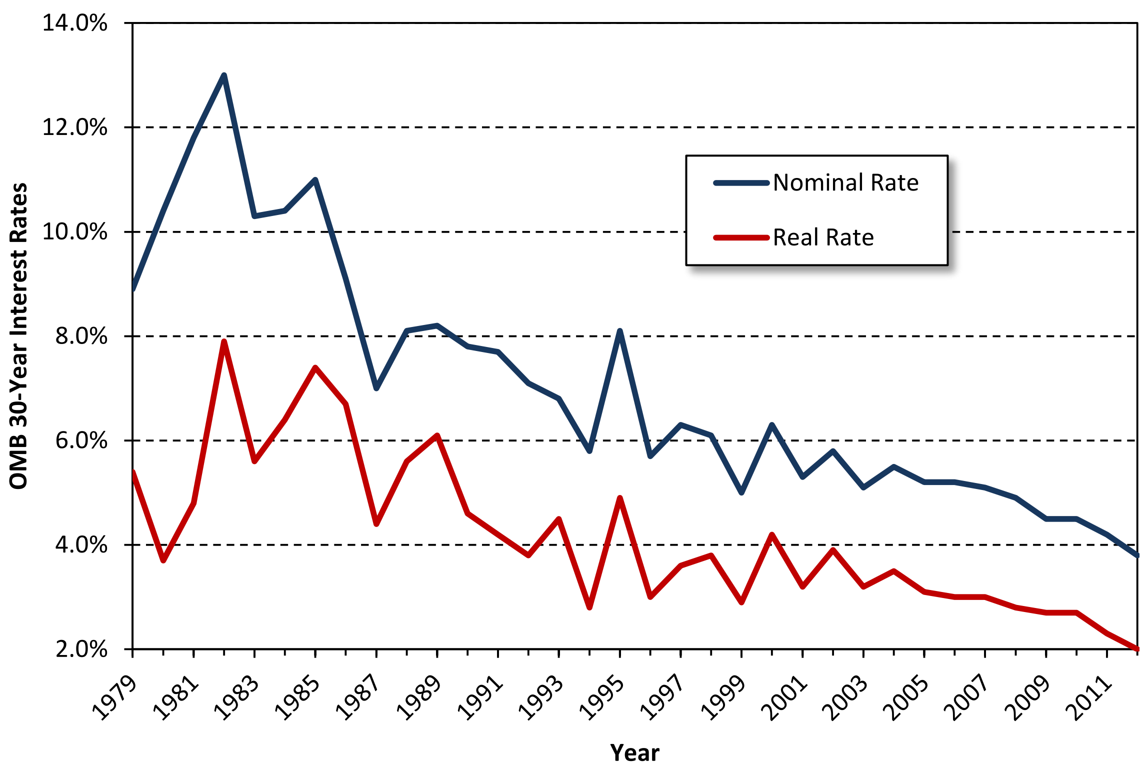

Figure 4.5 OMB 30-Year Interest Rates *(22)*

FHWA has also provided guidance on real discount rates for use in LCCA. The 1998 FHWA LCCA technical bulletin stated that "LCCA should use a reasonable discount rate that reflects historical trends over long periods of time. Data on the historical trends over very long periods indicate that the real time value of money is approximately 4 percent." The bulletin also noted that "3 to 5 percent is an acceptable range." The 2002 FHWA LCCA primer noted that "Real discount rates used in life-cycle cost analysis typically range from 3 to 5 percent, representing the prevailing rate of interest on borrowed funds, less inflation."

A memorandum FHWA released in 2008 stated that "Future agency costs should be discounted to NPV or equivalent uniform annual costs using appropriate (real) discount rates. Discount rates should be consistent with OMB circular A-94 *(56)*. The trend over the past 10 years indicates a discount rate in the range on 2-4 percent is reasonable."

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 4.5.1 shows the results of a comprehensive 2010 survey by the State Asphalt Pavement Associations *(16)*.

Table 4.12 State Asphalt Pavement Associations Survey of Discount Rates Used in LCCA (2010)

State	Discount Rate, %	State	Discount Rate, %
Alabama	4.0	Missouri	2.3
Arizona	4.0	Montana	4.0
Arkansas	3.8	Nevada	4.0
California	4.0	New Hampshire	4.0
Colorado	3.5	New Jersey	4.0
Delaware	3.0	New Mexico	4.0
Florida	4.0	New York	4.0
Georgia	3.0	Nebraska	2.4
Hawaii	4.0	North Carolina	4.0
Idaho	4.0	Ohio	2.8
Illinois	3.0	Oregon	4.0
Indiana	4.0	Pennsylvania	6.0
Kansas	3.0	Rhode Island	4.0
Kentucky	4.0	South Dakota	7.1
Louisiana	4.0	Tennessee	4.0
Maine	4.0	Utah	4.0
Maryland	4.0	Vermont	4.0
Massachusetts	3.0	Virginia	4.0
Michigan	2.8	Washington	4.0
Minn < 7MESALS	3.5	West Virginia	3.0
Minn > 7MESALs	3.5	Wisconsin	5.0
Mississippi	4.0	Wyoming	4.0

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

4.5.5. Measurement Issues

Economists have developed the concept of the real interest rate and developed means to estimate its value *(57)*. However, policymakers should be cognizant that the analyst cannot directly observe the real interest rate. Economists base estimates on the best available proxies that are subject to significant measurement issues.

Common practice is to begin with the two main factors: the interest rate and inflation rate. For the interest rate, OMB begins with the interest rates on Treasury Notes and Bonds with maturities ranging from five to 30 years. The concept is that this interest rate is relatively risk free in that the probability that the US Federal government will default is close to zero. However, fiscal and monetary policies as well as inflation heavily affect the interest rates on US Treasury bills.

OMB obtains real interest rates by removing inflation from nominal Treasury interest rates. Theoretically, the inflation that OMB should subtract is the expected inflation over the period of the analysis. In practice, OMB and most others use the actual rate of inflation for the current year. The use of actual rather than expected inflation potentially introduces error into the calculation. While the federal government allocates substantial resources to the measurement of inflation, it is an estimate, not a directly observable number, which also potentially introduces error into the calculation.

The FHWA LCCA primer illustrates the magnitude of the measurement issues. The primer states "Because there is always an opportunity value of time, real discount rates will always exceed zero." However, due to recent low interest rates, the last two 3-year real interest rates OMB published have been zero. In 2012, interest rates have dropped even more, raising questions as to whether OMB will begin publishing negative 3-year real interest rates and setting 5-year and 7-year real interest rates to zero or below.

4.5.6. Trends in the Real Interest Rate

One aspect of the real interest rate is whether it has a trend, in particular whether it is falling and analysts should expect it to stay at a low level. Some analysts have noted that in recent years real interest rates have been dropping. However, longer-term observations show that real interest rates have a more cyclical nature. Disagreements exist over whether the current low real interest rates reflect a true lowering, a temporary phenomenon of the business cycle, or a reflection of increased intervention and active policymaking by the Federal Reserve Board resulting from the great recession.

Federal Reserve Board Vice Chairman Roger Ferguson noted the cyclical nature of real interest rates stating, "Decisions about the sample period--whether to include low-real-rate stretches, such as the 1950s, or high-rate periods, such as the early 1980s--have material bearing on the estimate. This indicates to me that there can be significant and persistent deviations in the equilibrium real rate from the observed long-run average measured over decades. The average interest rate that seems to have brought aggregate demand and aggregate supply into rough balance in the past may not be the same rate required in every conjectural setting *(58)*." He concluded that, "Several aspects of the current outlook lead me to suspect that the return of the equilibrium real rate from its currently somewhat depressed level to its long-run value might plausibly be expected to be gradual and attenuated compared with historical experience."

This raises the parallel concern as to whether the selection of the real discount rate should reflect strictly current economic conditions or expected economic conditions over the 35 to 50 year period typical for LCCAs. For example, FHWA's Economic Analysis Primer states, "The agency should consider, however, that the discount rate applies over the life of the project, and adjusting the discount rate to reflect short-term funding fluctuations may distort the value of long-term benefits and costs *(54)*."

Employing a new single-year Circular A-94 real interest rate every year introduces considerable inconsistency into LCCAs. OMB's calculated real interest rate fluctuates up and down both in broad cycles and year-to year. 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. In over half of these 34 years, the real interest rate from one year to the next has changed by 0.7 percent or more. Adoption of a single year real interest rate could result in LCCA results that vary widely from the end of one year to the beginning of the next.

ALDOT will often conduct LCCA's a year or more in advance of actual project construction due to lag times in plan development, bid advertising, bid letting and project start dates. Use of single year real interest rates may result in the application of an abnormally high or low real discount rate to a project that the state actually constructs in a later year where inflation, economic growth and other variables have moved to conditions that are more normal.

4.5.7. Recommendations

It is recommended that ALDOT follow all of FHWA's guidelines. These include that "discount rates should be consistent with OMB Circular A-94," that "discount rates should reflect historical trends over long periods of time," and include a specific mention concerning "the trend over the past 10 years." The Colorado DOT currently uses this recommended policy of using a 10-year moving average of the OMB 30-year real interest rate as the real discount rate. It results in a real discount rate that is in the middle of the range of real discount rates selected by other states and provides a process where it is likely to remain a moderate assumption. However, it still reflects the latest real interest rate and keeps the real discount rate current without subjecting the real discount rate and LCCA results to extreme year-to-year fluctuations. Figure 4.6 shows the relative stability of the 10-year moving average versus the selection of a single-year's rate.

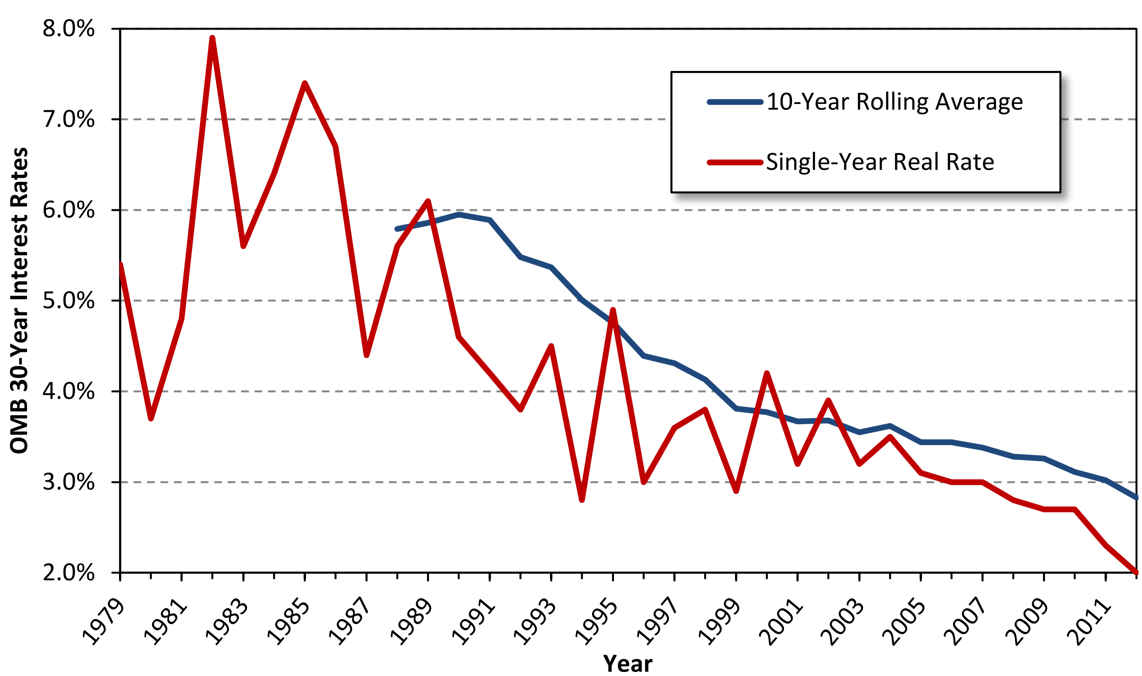

Figure 4.6 OMB 30-Year Real Interest Rates with 10-Year Moving Average

It is not recommended that ALDOT adopt the single-year OMB rates, as it would result in utilizing a real discount rate that: (1) ignores the significant measurement problems with real interest rates; (2) is at the low end of the real discount rate range used by other states; and (3) endangers the consistency and reliability of LCCA results. In contrast, use of a rolling average of OMB rates is more reflective of FHWA guidance and provides stable results while remaining consistent with recent economic conditions. This translates into more stable pavement type selections and more stable construction and materials markets. The current 10-year rolling average of the OMB discount rate is 2.83%.

4.6. Material Specific Inflation Rates

4.6.1. Introduction

Cement industry advocates have recently recommended the use of accounting procedures in LCCA that apply different rates of inflation to asphalt and concrete paving materials (*59*, *60*).

The use of material-specific inflation or discount rates is not accepted as a valid methodology within the economics profession. None of the economic journals, academic papers, or federal guidelines reviewed during this effort endorsed or even mentioned the concept of a material-specific discount rate (*61*-*65*). In fact, no mention of this terminology was found outside the papers written by the Concrete Sustainability Hub funded by the cement industry (*60*).

A memorandum issued on Sept. 20, 2012 by the White House Office of Management and Budget provided a clear message on the issue of discount rates used in LCCA (*66*). The memorandum states: "Regardless of any assumptions about relative prices and costs, all alternatives being compared should be discounted with the same discount rate following the guidelines in Section 9 of Circular A-94." In other words, OMB does not recommend overturning standard economic procedures in favor of a material-specific discount rate as proposed by the cement industry.

This section provides data that support NCAT's recommendations that ALDOT reject the notion of materials-specific discount rates in LCCA.

4.6.2. Actual Cost Data

Marketing information by the concrete industry has cited rising prices for asphalt binder in recent years to imply that inflation rates for asphalt pavement materials far exceed that of concrete paving materials. However, virgin asphalt binder only comprises about three to four percent of most asphalt paving mixtures. Actual asphalt mixture cost data were obtained from winning bids on all ALDOT projects since 2002. Asphalt binder price data for the same period were obtained from ALDOT's asphalt price index tabulation. These data are plotted in Figure 4.7. Since 2002, asphalt binder prices have increased 290%, or a compounded inflation rate of 14.6% per year. Average asphalt mix prices have risen by 109% during that period, a compounded inflation rate of 7.6% per year.

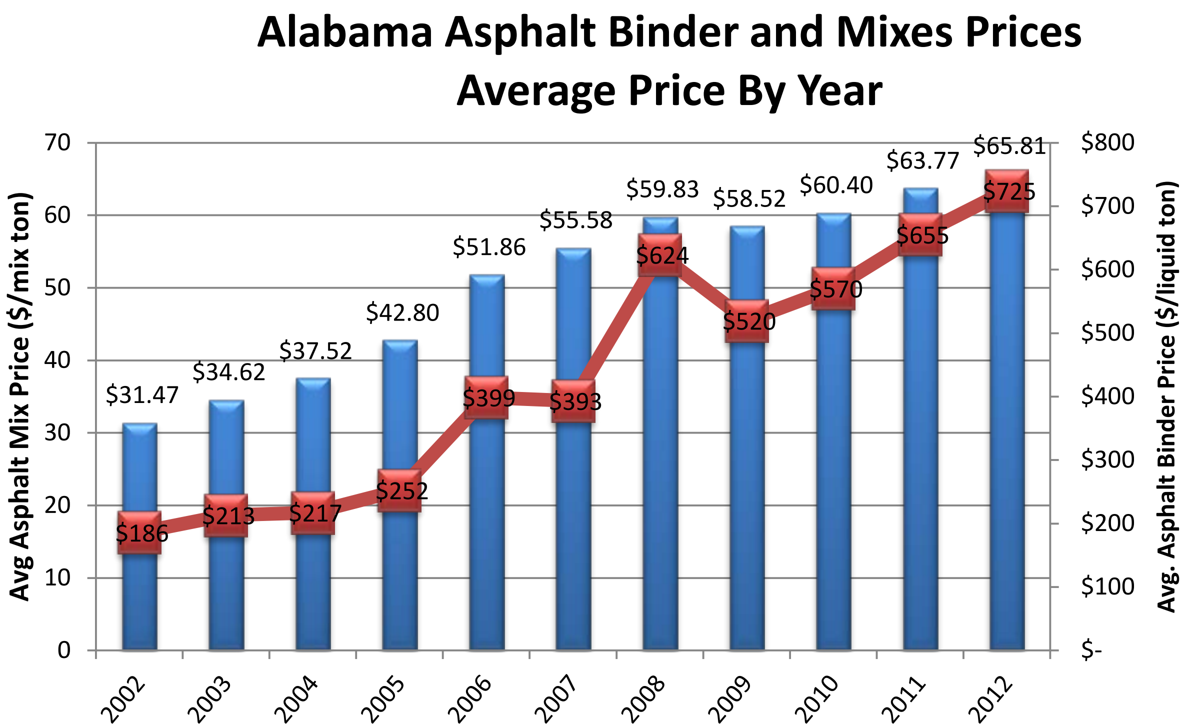

Figure 4.7 Average Asphalt Mix and Binder Prices from ALDOT Projects

Since ALDOT has done very few concrete paving projects over the past decade, the NCAT research team had to look elsewhere for cost information on concrete mixes and cement. Engineering News Record (ENR) provides a monthly construction materials cost report that includes ready-mixed concrete, cement, asphalt binder, etc. (*67*). The materials prices are reported for major cities including Birmingham, AL. Figure 4.8 is a graph of the average cost of concrete mixes and cement in Birmingham for each year since 2002. It can be seen that ready-mix prices have also risen by about 80%, or a compounded inflation rate of 6.7% per year. The increasing price trend would have continued to the present except for the housing slump since 2009 which cut cement demand. Of course, ready-mixed concrete and concrete paving mixtures are different products. Their mixture specifications are different, and paving concrete includes placement costs and other incidental items such as curing compounds and joint sawing. So data were obtained from the Georgia DOT for concrete paving bid items since 2000 (*42*). The only relevant bid item that appeared consistently in the data was their 12" Class 3 Jointed Plain Concrete Pavement, a typical interstate type concrete paving bid item. No data for this item was available in 2001. This average winning bid price data is graphed in Figure 4.9. It can be seen that from 2000 to 2010, this item increased by 89%, with an annual compound inflation rate of 6.5%.

Historical unit cost data for asphalt and concrete paving mixes have also been compiled for Missouri (*68*). The dataset goes back to 1992 and is graphed in Figure 4.10. This dataset is important because it illustrates that rates of inflation for any material will vary over time and trends over a few years or even a decade can be reversed over longer periods of time such as used in LCCA.

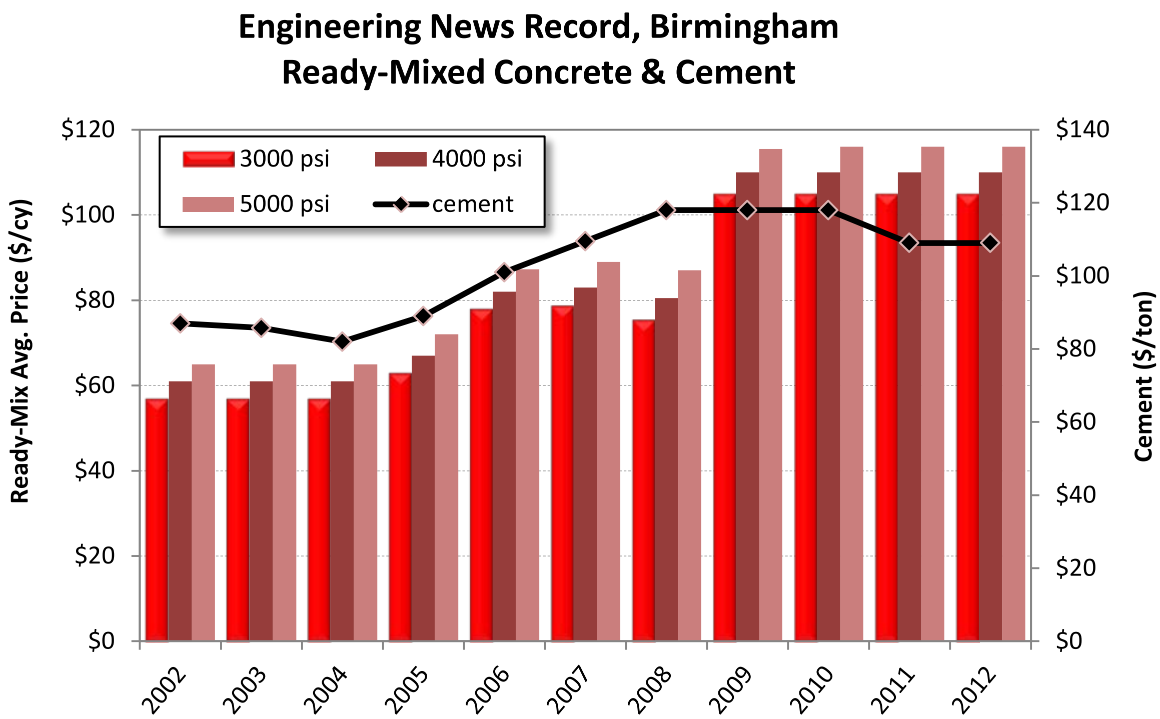

Figure 4.8 Annual Average Prices for Ready-Mix Concrete and Cement in Birmingham, AL

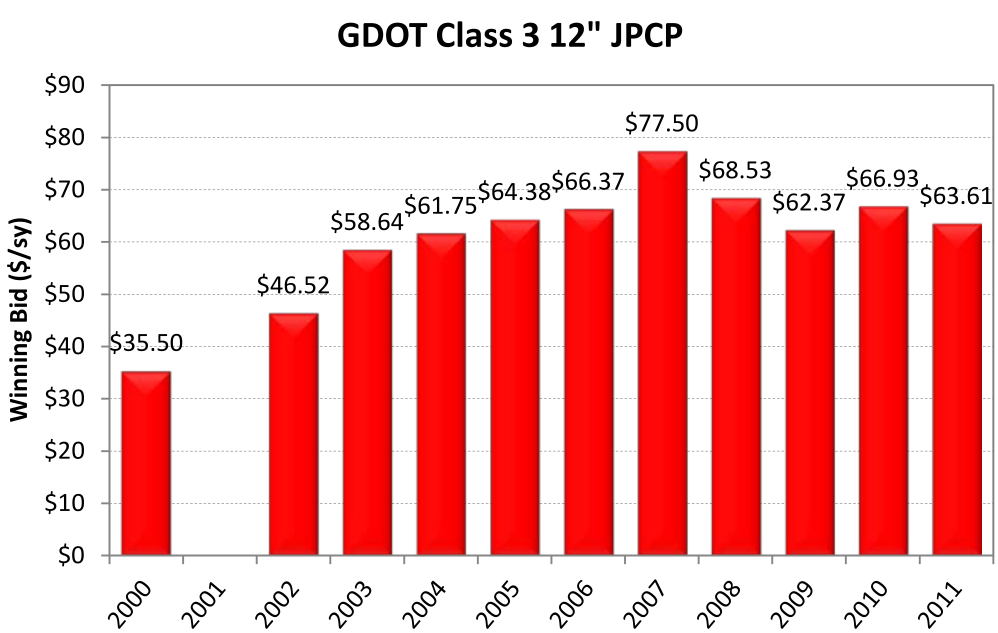

Figure 4.9 Average Winning Bid Prices for 12" Class 3 Concrete Paving in Georgia

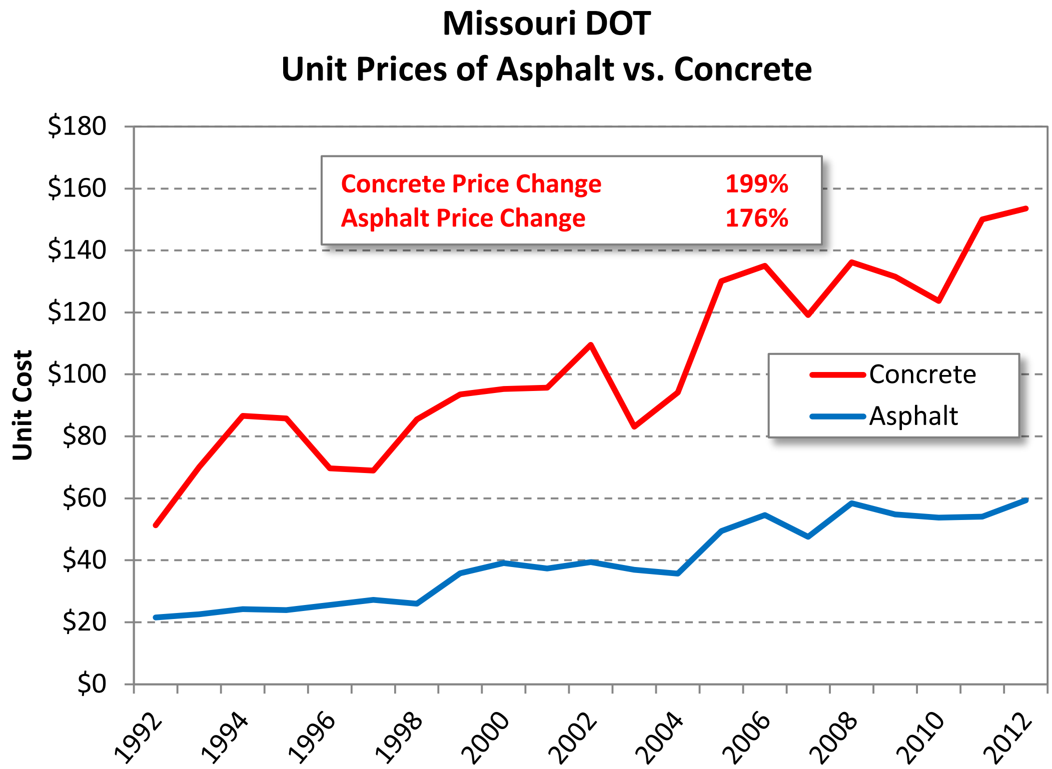

Figure 4.10 Average Unit Prices for Asphalt and Concrete Paving from 1992 to 2002

The material-specific inflation rate advocated by the concrete industry is not appropriate for use in LCCA because it assumes that such rates will remain constant throughout the analysis period. However, the key market factors that affected the construction related commodity prices in the past are likely to change in the future. In recent years, the United States has already witnessed increased domestic production of crude oil and natural gas through improved extraction technologies, a trend expected to continue, which will diminish volatility of crude oil prices caused by supply disruptions resulting from geopolitical unrest. Further development of other energy sources will also have a small but positive impact. Although energy demand will continue to rise, it will likely occur at a slower rate due to higher fuel-economy standards for passenger vehicles and the changing behaviors of consumers and industries regarding energy usage. More specifically for asphalt demand, increases in reclaimed asphalt pavement (RAP) and recycled asphalt shingle (RAS) contents of asphalt mixes will continue to diminish the quantities of virgin asphalt binder and aggregates needed for asphalt pavement construction. On the other hand, new EPA regulations on cement plants to curtail mercury and other pollutants will have a significant impact on domestic cement production costs. Furthermore, in the near future, Congress, EPA, and the courts will have to deal with regulations for fly ash, a hazardous by-product of coal combustion. Approximately 1/6th of the 72 million tons of fly ash produced annually is used in concrete to reduce the cement demand by 20 - 30%. The result will likely be much stricter handling requirements for fly ash that will impact the economic feasibility of using it in concrete products.

The available literature indicates that economists and academics are skeptical of the possibility of accurately predicting long-term commodity prices (*69*-*71*). This is true for any commodity such as oil, cotton, gold, asphalt or concrete. Therefore, most economists are dubious of material-specific inflation rates or ignore them outright. In response to a question regarding the utility of material-specific inflation rates posed at a U.S. Department of Transportation seminar, one transportation economist remarked, "I don't know how to do forecasts of future year inflation differentially… If you think you have a methodology to forecast differentially…don't work in this field. Go into the futures market. Make yourself some money." (*72*)

4.6.3. Recommendations

The NCAT team recommends that ALDOT reject the notion of materials-specific inflation rates in LCCA because of three reasons. First, the use of material-specific inflation or discount rates is not recognized as valid practice by the economics profession and is not endorsed in any government literature. Second, available data do not indicate that inflation rates for asphalt paving mixtures and concrete paving materials differ significantly over the past 10 to 20 years. Third, it is impossible to accurately predict future general inflation, much less the future values of particular commodities, beyond the short term. Attempting to predict specific commodity prices or even general inflation rates over any significant length of time is a foolish venture.

4.7. Asphalt Price Index

4.7.1. Introduction

Price adjustment clauses, also commonly known as price indexes, are widely used by most state highway agencies for fuel and asphalt binder. ALDOT has used an asphalt price index since the late 1970's following the Arab Oil Embargo to reduce the risk to contractors who bid on work that includes commodities with volatile prices. The concrete paving industry opposes the use of price indexes for asphalt because they claim that bids do not fairly reflect the actual cost of the work. This claim is not true; actually, the asphalt price indexes provide ALDOT several benefits. First, reducing the risk to contractors lowers bid prices that result from reduced uncertainty and more bidders, some of whom would otherwise be unwilling or unable to assume the risk of potentially higher asphalt prices. Second, when the prices on the indexed item go down, the Department also benefits by the reduced cost of that item. Third, removing asphalt price risk from contracts can focus contractors on delivering high quality works rather than meeting the "bottom line."

4.7.2. Current Practices

Price adjustment clauses (PACs) are widely used by state DOTs nationwide. AASHTO's 2009 *Survey on the Use of Price Adjustment Clauses* found that 47 states use price adjustment clauses on at least one construction input. More than 40 states reported using PACs for both fuel and liquid asphalt. NCHRP commissioned a review of price adjustment clause use and recommended best practices (*73*). This effort included surveying state DOT officials and highway contractors on their PAC programs. The survey found widespread support for PACs among each group of stakeholders. For example, 44 out of 46 responding state DOTs believe that PACs provide benefits for the DOT itself. All but one state DOT believes that they benefit prime and subcontractors. Table 4.13 presents a summary of state DOT responses.

Table 4.13 DOT Perceptions of PAC Benefits

Stakeholder	No Benefit	Small Benefit	Moderate Benefit	Large Benefit	n=
DOT/Owner	4.3%	34.8%	50.0%	10.9%	46
Prime Contractors	6.5%	13.0%	47.8%	32.6%	46
Subcontractors	6.5%	23.9%	45.7%	23.9%	46
Suppliers	23.8%	16.7%	40.5%	19.0%	42

Table 4.14 presents contractor perceptions of PACs. Again, over 90 percent of the respondents believe that PACs provide benefits for both themselves and their state DOTs. Contractors also reported that obtaining fixed prices from suppliers is a significant problem. A total of 44 percent of responding contractors believe it is a major problem and 29 percent state it is a moderate problem. Support for price adjustment clauses is strong regardless of material or commodity input.

The NCHRP report also applied a statistical model to historical construction bid tab data. This analysis indicated that the use of fuel and liquid asphalt price adjustment clauses resulted in lower bid prices for the Missouri Department of Transportation. Missouri, like Alabama, utilizes a zero-value trigger clause, which means that the price adjustment is applied with any upward or downward change in prices.

Table 4.14 Contractor Perceptions of PAC Benefits

Answer Options	No Benefit	Small Benefit	Moderate Benefit	Large Benefit	n=
DOT/Owner	5.3%	13.2%	40.8%	40.8%	76
Prime Contractors	5.3%	11.8%	21.1%	61.8%	76
Subcontractors	2.7%	13.3%	33.3%	50.7%	75
Suppliers	10.8%	10.8%	27.0%	51.4%	74

Additional sources confirm the utility of price adjustment clauses. A second AASHTO survey, entitled *Price Supply Issues, Alternate Bidding Issues, Practices for Increasing Competition* (*74*), received responses from 37 state DOTs and three non-DOT transportation agencies. The survey asked these agencies to select the techniques they used to increase bidding competition in their states. "Using price adjustment clauses for certain materials" received the second-highest number of responses (28 out of 40).

Two recent reports by researchers at the University of Oklahoma buttress the argument for the use of price adjustment clauses. The writers applied statistical analysis to bid data collected by the Oklahoma Department of Transportation (ODOT) between 2003 and 2009. Using this simulation, the writers of the first paper (*74*) determined that the winning low bids on asphalt items relative to other items were 11.7 percent lower during the observation period, 12.7 percent lower for PAC-eligible items relative to ineligible items, and 14.5 percent lower on eligible items relative to fuel-related items.

The second paper (*75*), which explored the impact of an asphalt binder price adjustment clause in Oklahoma on contractor bidding patterns and survival, concluded that, "The indexation of selected input prices has induced more aggressive bidding especially from small firms, further confirming the stylized notion that they are generally faced with more adverse liquidity constraints, and have more to gain when investment risks are reduced. Small firms are also exhibiting similar competitive behavior to larger ones in the post-policy period. The survival prospect for small entrants has been significantly improved after the policy was implemented, where the positive change is unique to entering firms that have been bidding on policy-eligible asphalt projects."

4.7.3. Recommendations

Price adjustment clauses are an established and popular method of ensuring a share of risk in construction contracting. A sampling of surveys with stakeholders and academic research each confirm their utility. Their benefits, which are recognized by large majorities of relevant stakeholders, include increased competition, lower bids, and necessary stability for smaller contractors. The inclusion of PAC provisions in highway procurement contracts is encouraged, especially on materials that may exhibit price fluctuations and volatility. Since the asphalt price indexes are straight forward and transparent and do not unnecessarily burden both the DOT and contractors, it should continuingly be used.

4.8. Salvage Value

4.8.1. Introduction

As discussed in Section 4.1, the recommended Analysis Period is 35 years to include the removal or in-place demolition of concrete pavements as they reach their terminal serviceability by the end of the Analysis Period. However, asphalt pavements will still be in service and requires only periodic surface renewal. Hence, the cost of removing concrete pavements and the salvage value in terms of the remaining service life of asphalt pavements at the end of the analysis period should be accounted for in the LCCA. A method for taking into account the removal cost for the concrete pavement option and the salvage value for the asphalt pavement alternative is discussed in this section.

4.8.2. Salvage Value Defined

According to FHWA's interim bulletin on LCCA (*2*), salvage value is value of a pavement alternative at the end of the analysis period. It composes of two components, as follows:

- Serviceable Life, which is the remaining service life of a pavement alternative at the end of the analysis period. This is the more significant salvage value component.
- Residual Value, which is the net value from recycling the pavement. The residual value is much smaller than the serviceable life.

4.8.3. What is Remaining at the End of the Analysis Period for Asphalt and Concrete Alternatives?

As discussed in the Section 4.1, many old concrete pavements in Alabama have been removed from service by rubblization or break and seat or have passed the acceptable threshold for pavement roughness. However, asphalt pavements built in the same time periods are still in service with periodic resurfacing to maintain a high level of serviceability. This cycle of surface rehabilitation is expected to continue indefinitely with longer periods between rehabilitations as improvements in asphalt paving technologies provide greater resistance to distresses.

As recommended in Section 4.1, the LCCA analysis period should be slightly longer than the typical serviceable life of concrete pavements. This means that concrete pavements will be removed at the end of the analysis period because they can no longer be feasibly maintained at an acceptable level of service. On the other hand, a monetary salvage value should be credited to asphalt pavement alternatives at the end of the analysis period because much of the original asphalt structure will continue to be a primary element of the pavement indefinitely. In addition, if the asphalt pavement is resurfaced near the end of the analysis period, that portion of the overlay's remaining service life beyond the analysis period should also be recouped in the LCCA. The methods for including the removal cost and salvage values in the LCCA follows.

4.8.4. Methods for Taking into Account Removal Cost and Salvage Value

Figure 4.11 shows potential expenditures for a concrete pavement alternative that should be considered in the LCCA. The removal or rubblization cost occurs at the end of the analysis period. Equation 4.1 is used to calculate the Net Present Value (NPV) of the expenditures shown in Figure 4.11 for the concrete pavement option.

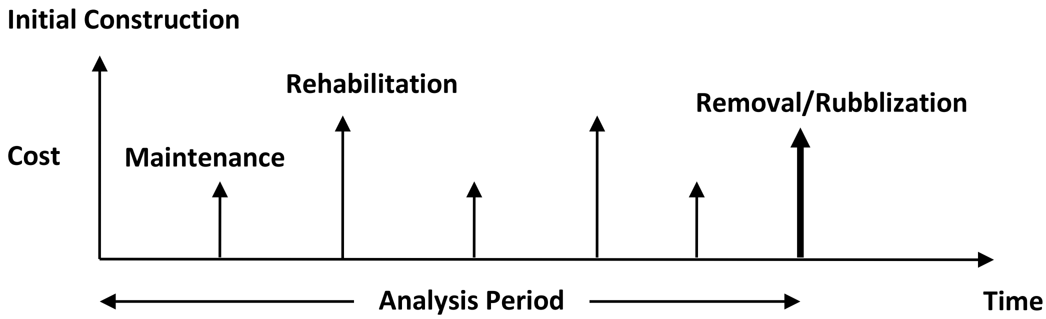

Figure 4.11 Stream of Potential Expenditures for Concrete Pavement

$$NPV_{PCC} = Initial\ Const. Cost + \sum_{k=1}^{N} Future\ \ Cost_k \left[\frac{1}{(1+i)^{n_k}}\right] + Rem.\ or\ Rub. Cost \left[\frac{1}{(1+i)^{n_e}}\right] \quad (4.1)$$

where:

- N = Number of rehabilitation/maintenance 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, year

Figure 4.12 shows potential expenditures and salvage value for an asphalt pavement alternative that should be considered in the LCCA. Equation 4.2 is used to calculate the Net Present Value (NPV) of the expenditures and salvage value for this alternative.

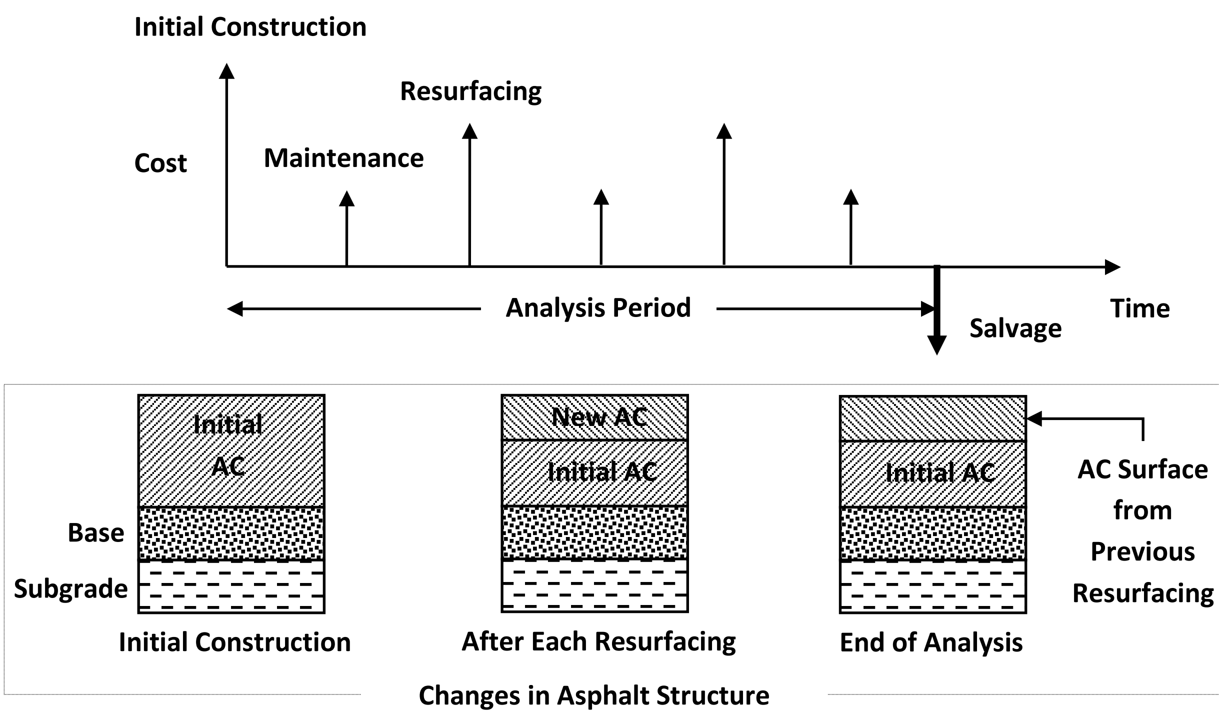

Figure 4.12 Stream of Expenditures and Salvage Value and Changes in Asphalt Structure for Asphalt Pavement

$$NPV_{AC} = Initial\ Const.Cost + \sum_{k=1}^{N} Future\ \ Cost_k \left[\frac{1}{(1+i)^{n_k}}\right] - Salvage\ Value \left[\frac{1}{(1+i)^{n_e}}\right] \quad (4.2)$$

where:

- N = Number of resurfacing/maintenance 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, year

As shown in Figure 4.12, at the end of the analysis period, the remaining asphalt structure is composed of two portions, as follows:

- The remaining wearing surface from the previous resurfacing.
- The lower asphalt layer that is remained from the initial construction because the periodic surface renewal is done in response to distresses confined to the top of the pavement.

Hence, the salvage value (Equation 4.3) for the asphalt pavement alternative will include two components:

- Value of the remaining service life of the wearing surface from the previous resurfacing.
- Value of the lower asphalt layers remaining from the initial construction.

$$Salvage\ Value = CLR \times \frac{Remaining\ Life\ of\ Last\ Resurf.}{Service\ Life\ of\ Last\ Resurf.} + CRI \quad (3)$$

where:

- CLR = Cost of the last resurfacing
- CRI = Cost of the lower asphalt layers remaining from the initial construction

4.8.5. Example

The following example is provided to illustrate how removal costs for concrete pavements and salvage values for asphalt pavements should be incorporated in LCCAs in the future. This example is based on the LCCA that ALDOT did for the I-20 project in Irondale from I-59 to Kilgore Memorial Drive. It should be noted that this example does not include other recommendations NCAT has provided in this report but is used to illustrate the salvage value recommendation.

Project Description

Project Location:	I-20 from I-59 to Kilgore Memorial Dr.
Analysis Period:	28 years
Project Length:	1.7318 mi
Discount Rate:	4%
Number of Traffic Lanes in One Direction:	2
Traffic-Lane Width:	24 ft
Inner Shoulder Width:	4 ft
Outer Shoulder Width:	10 ft

Alternative 1: Remove Old PCC and Replace with Full Depth HMA

Initial construction (Year 0):	Construct a new 17.6-in. full depth HMA pavement plus striping Initial performance period is 12 years
Rehabilitation 1 (Year 12):	Mill and replace 1.4-in. wearing layer plus re-striping Rehab-1 performance period is 8 years

Rehabilitation 2 (Year 20): Mill and replace 1.4-in. wearing layer and 2.34-in. upper binder layer plus re-striping
Rehab-2 performance period is 8 years
Salvage (Year 28): End of analysis period.
The bottom 13.86-in. HMA layer is still intact from the initial construction because the periodic surface renewal is done in response to distresses confined to the top of the pavement.

NPV Calculation:

Activities	Year	Non-Discounted	Discounted
Initial Const.	0	$ 2,456,218.34	$ 2,456,218.34
Rehab 1	12	$ 273,339.85	$ 170,727.26
Rehab 2	20	$ 640,245.50	$ 292,199.69
Salvage	28	$ (1,865,744.72)	$ (622,183.83)
NPV for HMA			**$ 2,296,961.46**

* The costs of initial construction and rehabilitations 1 and 2 were calculated in the ALDOT analysis.

Calculation of salvage value for the bottom 13.86-in. HMA layer:

Material Description	Thickness (in)	Quantity			Unit Cost	Amount
		T.L.	I.S.	O.S.		
240 #/SY Lower Binder 424B	2.16	2923	609	1340	$ 56.56	$ 275,560.32
250 #/SY Lower Binder 424B	2.25	3045	698	1459	$ 56.56	$ 294,225.12
350 #/SY Lower Binder 424B	3.15	4263	1066	2131	$ 56.56	$ 421,937.60
350 #/SY Lower Binder 424B	3.15	4263	1155	2220	$ 56.56	$ 432,005.28
350 #/SY Lower Binder 424B	3.15	4263	1243	2309	$ 56.56	$ 442,016.40
Total	13.86					$ 1,865,744.72

<u>Alternative 2: Remove Old PCCP and Replace with New PCCP</u>

Initial construction (Year 0): Construct a new 14-in. PCCP with 6” HMA base plus striping
Initial performance period is 20 years
Rehabilitation 1 (Year 20): Clean and sealing
Rehab-1 performance period is 8 years
Salvage (Year 28): End of analysis period.
The PCCP pavement is removed as it has reached its terminal serviceability.

NPV Calculation:

Activities	**Year**	**Non-Discounted**	**Discounted**
Initial Const.	0	$ 3,075,123.77	$ 3,075,123.77
Rehab 1	20	$ 324,700.03	$ 148,188.86
Removal	28	$ 222,239.00	$ 74,111.70
NPV for PCCP			**$ 3,297,424.32**

* The costs of initial construction and rehabilitation 1 were calculated in the ALDOT analysis. The removal cost in this example is calculated as follows:

Removal Cost = PCCP Surface Area * Unit Price for Removal
= 33,170 SY * $6.70/SY = $222,239.00

where:

PCC Surface Area for 2 Traffic Lanes, Inner & Outer Shoulders =
18,946 SY + 4,064 SY + 10,160 SY = 33,170 SY

4.9. User Costs

4.9.1. Introduction

User Costs are the extra costs incurred by the vehicle operators traversing a facility under construction. The costs are important to consider on behalf of the public but are ultimately tough to accurately predict. Guidance given by the FHWA on calculating User Costs is straightforward *(2)*, but some assumptions are oversimplified. ALDOT should consider User Costs only when the Net Present Value of the design alternatives are within 10% of each other or if it excessively long queues are expected during any part of construction, rehabilitation, or removal/demolition.

4.9.2. Calculation of User Costs

User Costs are costs incurred by highway users traveling on the project under consideration for LCCA or users who cannot travel on the project due to agency or self-imposed detour requirements. User Costs consist of three components: Vehicle Operating Costs (VOC), Crash Costs, and User Delay Costs. The FHWA has provided extensive guidance on calculating User Costs.

Before User Costs can be computed, 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:

1. *Project Future Year Traffic Demand*

    - Base year Annual Average Daily Traffic (AADT)
    - Percent Passenger Vehicles
    - Percent Single-Unit Trucks
    - Percent Combination Trucks
    - Traffic Growth Rate

    ALDOT has this information readily available for any reconstruction project. For new construction projects estimates would be required.

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.

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. Work Zone Capacity can be estimated from past experience, or values from the *Highway Capacity Manual (76)* can be used (Table 4.15). Queue dissipation rates average 1,818 pcphpl with a standard deviation of 144 pcphpl.

Table 4.15 Work Zone Capacities from the *Highway Capacity Manual*

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 in to consider the difference in the amount of time required to traverse the work zone under the reduced speed and to subtract 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.

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.

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 off data from NCHRP Report 133 (1970) and NCHRP Project 7-12 *Microcomputer Evaluation of Highway User Benefits* (1993). The FHWA takes both recommendations 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 (October 2012) values.

Table 4.16 FHWA User Delay Rates

Vehicle Type	**Value of Time ($/hr)**	
	Aug-96	**Oct-12**
Passenger Cars	11.58	17.61
Single-Unit Truck	18.54	28.20
Combination Trucks	22.31	33.93

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 $0.47 per mile (Oct-12$) 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 $1.89 million for fatalities, $42,000 for injuries and $5,420 for property damage (all Oct-12$). 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.

4.9.3. Common Practice

A 2005 study commissioned by the South Carolina DOT (*11)* found that 41% of states responding to their survey used User Costs to some extent when calculated the Life-Cycle Cost of a design alternative. Some states reported only considering User Costs in certain situations—when one alternative creates large traffic queues or the two alternatives' NPVs are within 10% of each other.

4.9.4. In Alabama

Traffic projections are the most influential factor in a User Delay Cost sensitivity analysis. Traffic projections made by ALDOT between 1986 and 2011 could be off by as much as 40% within 20 years (see Section 4.1). 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.

A Life-Cycle Cost Analysis was performed for State Project IM-NHF-I065 (393), the reconstruction of I-65 in Hoover from I-459 to SR-3. The NPVs 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. The project was contracted to McCarthy Improvement Company, Inc. for $21,116,157. Construction began on 11 March 2011 and completed on 1 January 2012 (297 construction days).

At certain times during this reconstruction, acceleration lanes to merge onto the highway were not available. This resulted in approximately 500 accidents *(77)*. The majority of these accidents were minor and resulted in only property damage or minor injury. The Crash Costs attributed to these accidents would have a very significant effect on the LCCA, especially if the acceleration lanes were required to be closed for a longer period of time when constructing one of the design alternatives. 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 projects. Indeed, it does not take much to render a User Cost prediction inaccurate.

ALDOT routinely includes incentive/disincentive clauses in contracts to encourage quick completion, ostensibly to benefit the users by removing the Work Zone as quickly as possible. The incentive/disincentive amounts typically range between $15,000 and $30,000 per day and are calculated by estimating the Vehicle Operating Costs of traversing the nearest detour.

4.9.5. Recommendations

User Costs are important to consider in an LCCA, but ultimately tough to predict accurately. ALDOT should consider User Costs whenever the NPV of the two design alternatives are within 10% of each other, or whenever excessive queues will form during rehabilitation. FHWA's *RealCost* software and the *LCCA* software provided by the Asphalt Pavement Alliance include tools for estimating User Delay Costs. The LCCA software also includes a tool to optimize the timing of lane closures so that user delay costs are minimized.

5. EXAMPLE PROJECTS

5.1 Introduction

The section examines the effects on LCCA due to the proposed changes by the NCAT and UA teams 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 the NCAT team's recommendations.

It should be noted that these LCCA calculations are, in general, for one direction only. Also, the UA approach results in significantly larger NPVs than the NCAT recommendations or current ALDOT policies. It is important to note that the UA analysis has a significantly longer analysis period than NCAT's or ALDOT's. The comparison between the NPVs of alternatives matters in LCCA, not the magnitude of individual NPVs.

The following 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) Rehabilitation of Concrete Pavement, Project No. IM-0592(342) (MP 184.000-194.712)
- I-20 (Talladega) Pavement Rubblization, Additional Lane Added, Project No. IM-NHF-020-1 (MP 173-130)
- I-59 (Bessemer) Pavement Reconstruction from Alabama Adventure Parkway to North CSXT RR Overpass, Project No. IM-I059 (351) (MP 109.78- 110.98)
- Corridor X Walker Co. line to US-78, Project No. APD-0471(504)

5.1.1. Current ALDOT Policy

The current ALDOT procedure uses the following inputs:

- Analysis Period: 28 years
- Discount Rate: 4%
- Asphalt Initial Performance: 12 years
- Asphalt 1st Overlay Performance: 8 years
- Asphalt 2nd Overlay Performance: 8 years
- Concrete Initial Performance: 20 years
- Concrete Rehabilitation Performance: 8 years
- No Salvage Value considered
- No User Costs considered
- Deterministic Approach

Minor rounding errors occur when examining DARWin outputs versus those calculated in Excel (as they were for this analysis). DARWin rounds quantities to the nearest whole number, and these whole numbers were used in Excel calculations. The difference is always negligible.

5.1.2 NCAT Recommendations

NCAT recommends using the following inputs:

- Analysis Period: 35 years
- Discount Rate: 2.833%
- Asphalt Initial Performance: 19 years
- Asphalt Rehab Performance: 13.5 years
- Concrete Initial Performance: 35 years
- Concrete Maintenance at Year 20
- Remaining Service Life salvage value included
- Material Salvage Value Included (value of remaining asphalt, cost of slab removal)
- Agency Costs not Included
- User Costs determined as appropriate for specific project circumstances

5.1.3 UA Recommendations

UA has recommended the following inputs:

- Analysis Period: 50 years
- Discount Rate: 2.833%[1]
- Asphalt Performance Period: 12 years[2]
- Asphalt Rehab Period: 8 years[2]
- Concrete Performance Period: 20 years[2]
- Concrete Rehab Period: 8 years[2]
- Agency Costs considered after initial construction (estimated at 10% of pavement costs)
- Remaining Service Life salvage value included
- Material Specific Inflation Rate (MSIR) included (1.15% for Asphalt, -0.049% for Concrete)
- Asphalt Adjustment Multiplier included (1.02% for Asphalt)
- User Costs not considered

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 them by 0.56%). The MSIR applies to future rehabilitations involving asphalt and concrete materials.

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[1] UA originally recommended a Discount Rate of 2.0%, but agreed with NCAT's recommendation of using a 10-year rolling average during the December 7th, 2012 meeting in Montgomery.

[2] UA has not proposed changes in performance periods for asphalt or concrete— therefore, these are the current values used by ALDOT

5.2 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-IMD-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 to be built as concrete.

During construction, this section is shut down for 90 days, and traffic is detoured along I-459 and I-59. Construction began on September 11th, 2012 and is currently underway.

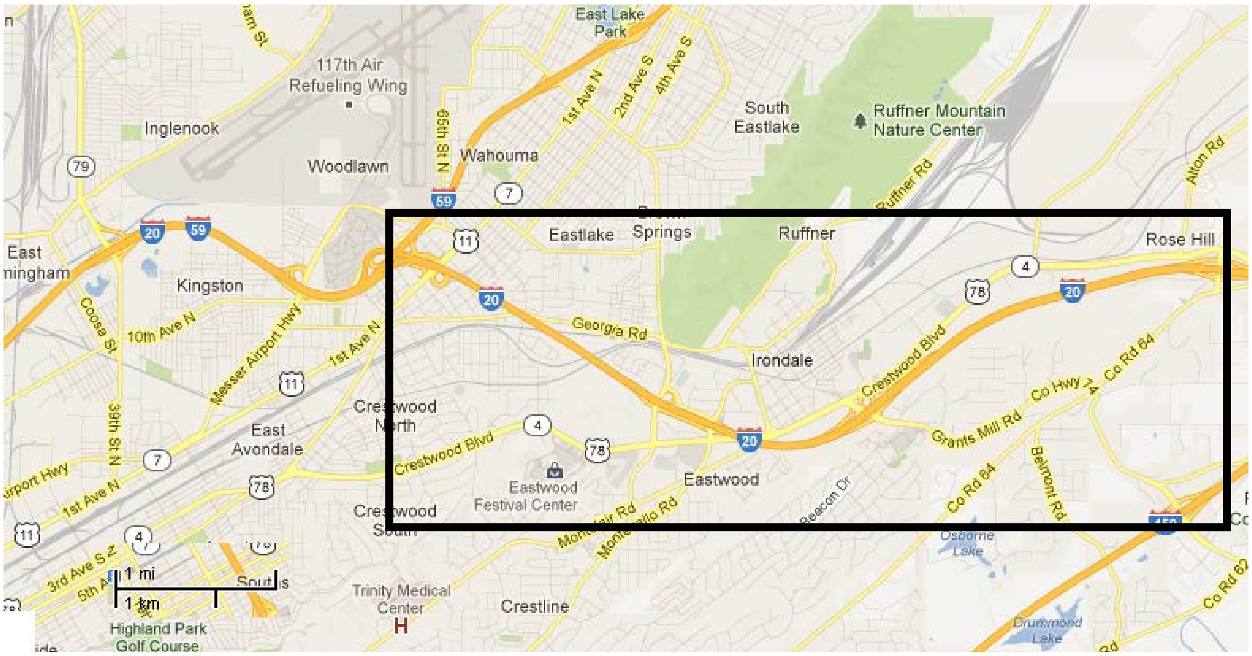

Figure 5.2.1 I-20 from I-59 to CR-64 in Birmingham, AL

5.2.1 Current ALDOT Policy

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**

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**

5.2.2 NCAT Recommendations

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.

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**

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**

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 $678,111,54 due to including a 3% slab removal and replacement and diamond grinding at year 20 ($469,385.99) and removal of the concrete pavement at year 35 ($150,706.16).

<u>User Costs</u>

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

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**

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**

The estimated user costs for the *rehabilitation* activities were similar for the asphalt and concrete options. However, the estimated user costs incurred during removal of the concrete at the end of its terminal life are very high even though those costs are discounted over 35 years. Readers should keep in mind that drivers who *currently* use this highway segment are being inconvenienced by approximately $4.5 million due to the detour necessary to remove and reconstruct this project now underway.

5.2.3 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**

Concrete Cost Schedule for I-20, Irondale				
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	$225,548.90
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	$151,881.75
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	**$7,070,109.26**

The UA Team recommendations increase the NPV of the asphalt option by about $2.1 million 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 $223,111.08. Third, including the UA recommended asphalt index adjustment factor and materials-specific inflation rate increases the asphalt NPV by over $800,000.

Using the same recommendations for the concrete option increased its total NPV by over $1.3 million. However, $823,085.57 of the increase was from the inclusion of 3% slab removal & replacement and diamond grinding as rehabilitation activities which were considered reasonable since the UA team provided no recommendations on concrete pavement rehabilitation. The UA team needs to recommend the performance periods for concrete pavements; LCCA should not be conducted if the performance periods for the concrete pavements are not specified. Engineering and construction management costs for the concrete rehabilitation activities totaled to $148,345.11.

Using the UA recommendations, the concrete option has a slight edge, but the NPVs of the two alternates are within 10%. If User Costs are considered is such cases, then the asphalt option is still the best overall choice for this project.

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

Project No. IM-I065(393) was the rubblization and reconstruction of an existing concrete pavement in Hoover, AL. The project contained 3-lane and 4-lane sections as well as six ramps. Ten LCCAs (4-lane north and south, 3-lane north and south, and six ramps) were performed by ALDOT using the DARwin software program. 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
- Slope paving used in wide median and gore areas
- 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 6600 psi, the design thicknesses were 16.25 in. for an asphalt pavement, and 16 in. for a concrete pavement. The result of the ALDOT LCCA calculation was close: the NPV of the asphalt option was $12,226,382 and the NPV for a concrete surface was $12,274,604 (a difference of 0.07%). At the direction of ALDOT Director Joe McInnes, the project was built as concrete.

It was noted in the User Cost discussion that this project experienced a high volume of crashes (approximately 500 within 297days). The cities of Vestavia and Hoover kept crash data during this project. These crashes occurred primarily in areas where traffic was forced to merge onto I-65 without an acceleration lane and therefore most were minor in nature.

U.S. Route 31 was used as a detour when the on/off ramps were closed at the I-65/I-459 and I-65/US-31 interchanges. Queues of two miles would regularly form during construction, although this is not uncommon as this is a very high-trafficked route (AADT 66,260).

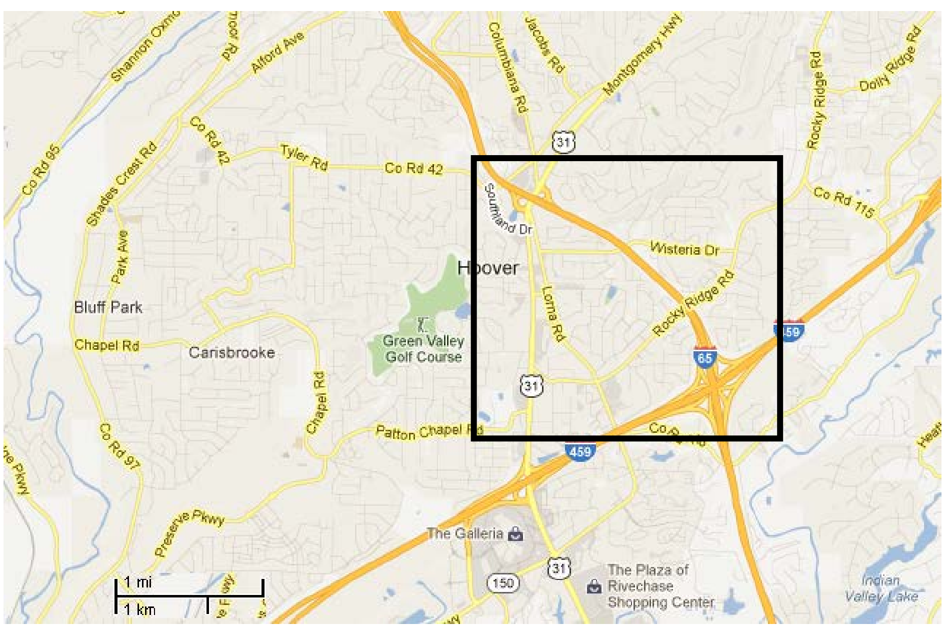

Figure 5.3.1 I-65 in Hoover, AL

5.3.1 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**

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**

These values differ slightly from those provided on the previous page due to differences in rounding by the LCCA programs used by ALDOT and NCAT.

5.3.2 NCAT Recommendations

Since this is an urban setting, it is assumed that the concrete pavement will require removal rather than rubblization at the end of its lifespan to avoid extensive adjustments to bridges, overpasses, drainage structures, barrier walls, etc.

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

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

Compared to the NPV from ALDOT's current policies, NCAT's recommendations reduced the NPV for the asphalt option for this project by $3,318,001.19. As with the first example, the difference is largely due to the salvage values for the asphalt pavement ($3,109,985.75) at the end of the analysis period. The longer service lives for the asphalt option reduced the NPV only by $208.015.44. For the concrete option, the NCAT recommendations increased the NPV by $1,978,874.13. That increase resulted from including 3% slab removal & replacement and diamond grinding at year 20 ($1,455,156.43) and removal of the concrete pavement at year 35 ($439,056.24).

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: 100,000 vpd

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**

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**

The estimated user costs for this project are much lower than the NPV of the agency costs. The relatively higher user costs for the concrete option are due to the fact that when the lane closures are required to remove the concrete pavement in year 35, the traffic has grown to a very high AADT.

5.3.3 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**

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**

The UA Team recommendations increase 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 $610,789.93 and the concrete option by $289,565.66. The asphalt index adjustment factor and materials-specific inflation rate increased the asphalt NPV by over $1.3 million.

5.4 I-59 (Etowah County) Reconstruction of Concrete Pavement, Project No. IM-0592(342) (MP 184.000-194.712)

A concrete section of I-59 in Etowah County required complete reconstruction in the spring of 2008. Three options were considered by ALDOT during the LCCA. ALDOT's calculated NPVs for each option are in shown in parentheses:

- Remove existing PCC and replace with PCC ($42,504,268)
- Unbonded PCC overlay with slab repair ($30,749,121)
- Rubblize existing PCC and replace with asphalt pavement ($24,962,890)

Although the asphalt alternative had the lowest NPV by $5.8 million (18.8%), the project was directed to be built as an Unbonded PCC overlay.

The project length was 10.7 miles and is two lanes in each direction.

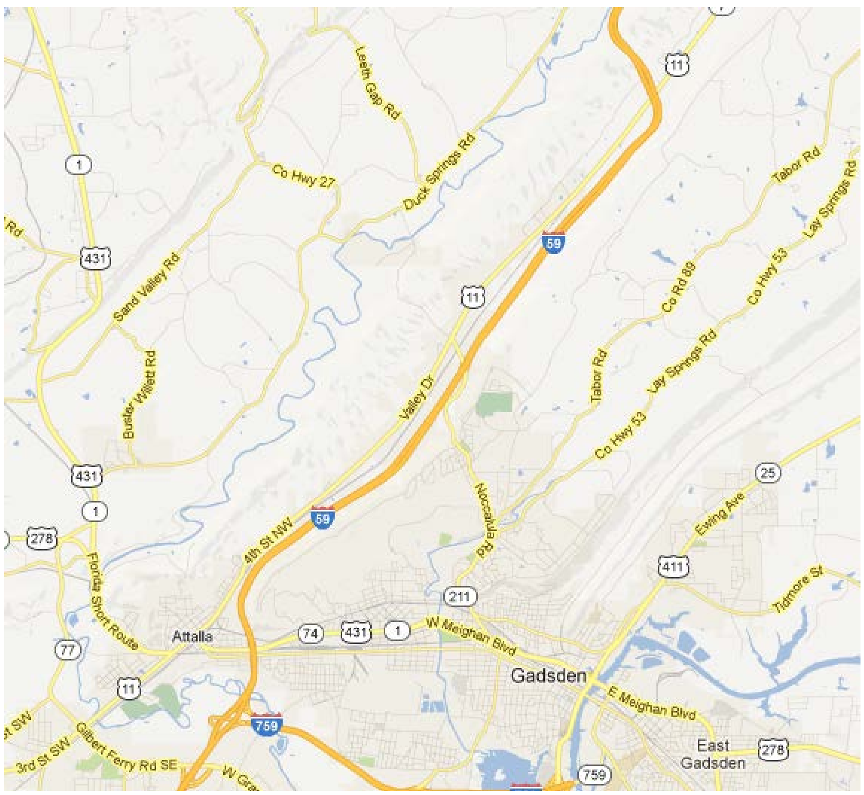

Figure 5.4.1 I-59 in Gadsden, AL (Etowah County)

5.4.1 *Current ALDOT Policy*

These costs exclude non-pavement costs (approximately $6 million) and only consider one direction of construction.

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**

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**

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**

5.5.2 *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**

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**

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**

The NPVs for the two concrete options differ only by the initial construction costs; the unbonded overlay does not require removal of the existing concrete pavement, which appears to make it the best choice of the two concrete alternatives. However, as discussed in section 4.3, the unbonded overlay changed the elevation of the roadway so much that practically everything else on the project had to be redesigned and adjusted which dramatically increased the total cost of the project.

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 the inclusion of the additional rehabilitation activities and the cost for rubblization of the concrete pavement at the end of the analysis period.

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%.

<u>User Costs</u>

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: 40,000

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**

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**

As with the previous example projects, the primary difference in user costs between the concrete and asphalt options is dealing with the concrete pavement at the end of its serviceable life. In this case, the pavement would likely be rubblized, but the lane closures to do that work under traffic that has increased over 35 years results in very high user delay costs.

5.5.3 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	**$20,436,394.95**

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	**$14,015,691.70**

Asphalt Cost Schedule, I-59 (Gadsden)				
Year	Activity	Cost	MSIR	NPV
0	Initial Construction	$6,924,782.65	$6,924,782.65	$6,924,782.65
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	**$15,400,926.06**

For the UA recommended changes to LCCA, the unbonded PCC overlay option appears to beat the worst case asphalt option by about 9%. However, as previously noted, the unbonded overlay option certainly had other significant project costs not included in this LCCA that were due to the roadway elevation change.

The Materials Specific Inflation Rate adjustment applied to the asphalt option increases its NPV by approximately $1.8 million. The addition of engineering and construction management costs increase the asphalt option by $625,022.49 compared to $305,845.54 for the unbonded concrete option. The salvage values calculated using the UA recommendations was essentially negligible for both options; it was less than 1% of the total NPV concrete option and 1.3% of the total NPV for the asphalt option.

5.5 I-20 (Talladega) Rubblization & Reconstruction with a Lane Added, Project No. IM-NHF-020-1 (MP 173-130)

An LCCA was conducted by ALDOT in April of 2001 for the rubblization, resurfacing and addition of lanes for Project No. IM-NHF-020-1 in Talladega County. The concrete option considered was an unbonded overlay. The NPV of the asphalt option was found to be $2.4 million lower (in one direction).

This asphalt project was built by McCartney Construction and was an extremely close runner up for the Sheldon G. Hayes award for the best asphalt pavement in America in 2008.

5.5.1 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**

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**

5.5.2 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**

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**

The salvage values used in the NCAT approach reduces the NPV of the asphalt option by $1,162,387.06, a reduction 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

Traffic data were not obtained to estimate user costs for this project.

5.5.3 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**

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**

The UA recommended LCCA inputs resulted in another close total for the asphalt and concrete options, with 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 do to having the amounts discounted over 50 years.

5.6 I-20/I-59 (Bessemer) Pavement Reconstruction from Alabama Adventure Parkway to North CSXT RR Overpass, Project No. IM-I059 (351) (MP 109.78 - 110.98)

An LCCA was performed for the reconstruction of I-59 in Bessemer 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 surface was CRCP and was rubblized. This pavement design therefore required bridges on the project to be raised 16 inches. These costs were not included in the LCCA as they apply to both pavement types.

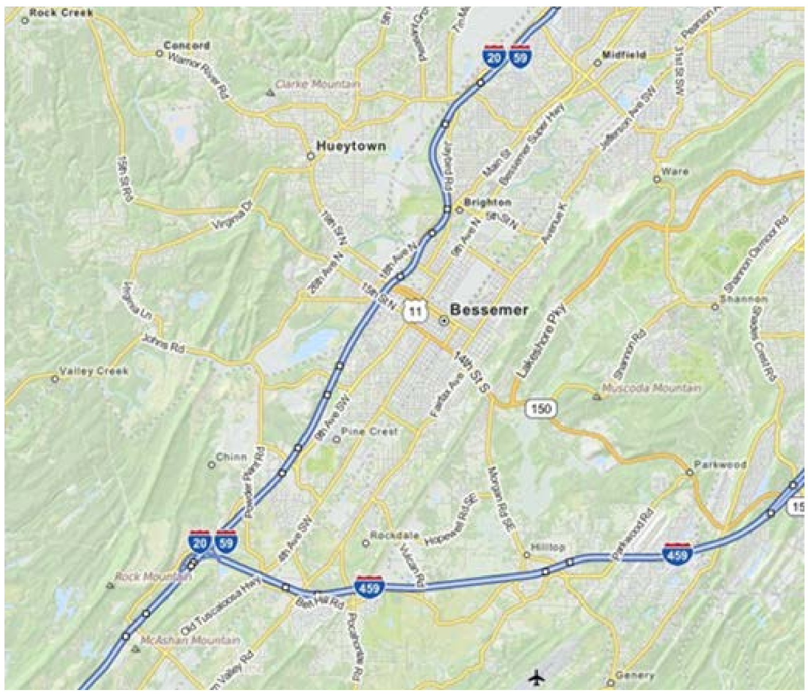

Figure 5.5.1 I-20/I-59 in Bessemer

5.6.1 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**

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**

5.6.2 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**

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**

<u>User Costs</u>

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: 100,000 vpd

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**

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**

5.6.3 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**

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**

5.7 Corridor X Alternate Design Alternate Bid

Corridor X was new construction between US-78 and the Walker/Jefferson County line. The project was let using an Alternate Design Alternate Bid Method. LCCA was used to determine how much should be added to the asphalt pavement option. Therefore, only rehabilitation costs were considered. LCCA were calculated using one quantities for one-direction.

5.7.1 Current ALDOT Policy

Using the current ALDOT LCCA policy, $2,495,230 (accounting for both directions) was added to the asphalt pavement bid prices.

Asphalt Rehabilitation Costs, Corridor X			
Year	Activity	Cost	NPV
12	1st Rehab	$1,416,875.98	$884,976.56
20	2nd Rehab	$1,403,389.98	$640,488.87
		Total	**$1,525,465.42**

Concrete Rehabilitation Cost Schedule, Corridor X			
Year	Activity	Cost	NPV
20	Rehabilitation	$608,804.00	$277,850.20
		Total	**$277,850.20**

5.7.2 NCAT Recommendations

Using NCAT's recommendations, $678,033 should have been added to the concrete pavement bid prices.

Asphalt Rehabilitation Costs, Corridor X			
Year	Activity	Cost	NPV
19	Remove/Replace 2 Layers	$1,416,875.98	$833,324.65
32.5	Remove/Replace 3 Layers	$1,403,389.98	$566,072.33
35	Remaining Service Life of Last Rehab	$(25,642.00)	$(9,645.27)
35	Residual Pavement Salvage Value	$(1,143,502.95)	$(430,129.85)
		Total	**$959,621.86**

Concrete Rehabilitation Cost Schedule, Corridor X			
Year	Activity	Cost	NPV
20	Rehabilitation	$1,954,878.22	$1,118,724.09
35	Rubblization	$477,816.02	$179,914.62
		Total	**$1,298,638.71**

5.7.3 UA Recommendations

Using the UA recommendations, $6,378,529 should have been added to the asphalt pavement bid prices.

Asphalt Rehabilitation Costs, Corridor X				
Year	Activity	Cost	MSIR	NPV
12	Milling 3 Layers	$105,670.98	$105,670.98	$75,572.83
12	Replacing 2 Layers	$1,311,205.00	$1,504,046.43	$1,075,650.47
12	Engr. & Mgmt. Cost	$141,687.60	$141,687.60	$101,330.87
20	Milling 3 Layers	$62,184.98	$62,184.98	$35,566.03
20	Replacing 3 Layers	$1,341,205.00	$1,685,826.61	$964,190.37
20	Engr. & Mgmt. Cost	$140,339.00	$140,339.00	$80,265.38
28	Milling 3 Layers	$62,184.98	$62,184.98	$28,443.00
28	Replacing 3 Layers	$1,341,205.00	$1,847,310.94	$844,947.72
28	Engr. & Mgmt. Cost	$140,339.00	$140,339.00	$64,190.12
36	Milling 3 Layers	$62,184.98	$62,184.98	$22,746.54
36	Replacing 3 Layers	$1,341,205.00	$2,024,263.76	$740,451.96
36	Engr. & Mgmt. Cost	$140,339.00	$140,339.00	$51,334.36
44	Milling 3 Layers	$62,184.98	$62,184.98	$18,190.94
44	Replacing 3 Layers	$1,341,205.00	$2,218,166.78	$648,879.33
44	Engr. & Mgmt. Cost	$140,339.00	$140,339.00	$41,053.30
50	Remaining Service Life	$(385,932.24)	$(385,932.24)	$(95,474.14)
			Total	**$4,697,339.07**

Concrete Rehabilitation Cost Schedule, Corridor X				
Year	Activity	Cost	MSIR	NPV
20	Rehab Activities	$392,299.56	$392,299.56	$224,371.51
20	Replace Concrete	$804,518.64	$729,590.52	$417,281.44
20	Engr. & Mgmt. Cost	$119,681.82	$119,681.82	$68,450.73
28	Rehab Activities	$758,060.02	$758,060.02	$346,731.60
28	Engr. & Mgmt. Cost	$75,806.00	$75,806.00	$34,673.16
36	Rehab Activities	$392,299.56	$392,299.56	$143,498.58
36	Replace Concrete	$804,518.64	$674,704.56	$246,799.02
36	Engr. & Mgmt. Cost	$119,681.82	$119,681.82	$43,778.21
44	Rehab Activities	$92,420.05	$92,420.05	$27,035.59
44	Engr. & Mgmt. Cost	$75,806.00	$75,806.00	$22,175.50
50	Remaining Service Life	($269,703.78)	($269,703.78)	($66,720.88)
			Total	**$1,508,074.46**

6. RECOMMENDATIONS

This section summarizes the NCAT team's significant findings and recommendations for each LCCA topic discussed in this report. The UA team's recommendations are also provided when they are available.

Table 6.1 LCCA Trigger Recommendations

Guidance	Recommendations	Discussion
No guidance is provided by FHWA or other federal authorities on when an LCCA should be conducted. Such polices among state DOT's vary considerably.	UA Team: All projects ≥ $3 million.	• A fixed dollar amount trigger becomes a greater burden on ALDOT over time due to the time value of money and inflation. • ALDOT would have to devote more staff to just do LCCA. • The concrete industry has not bid on competitive projects, wasting ALDOTs time and resources in pre-project engineering and design efforts. • On many projects, rehabilitation activities would be above the proposed $3 million trigger which would require repetitive LCCAs on the same project. • MAP-21 requires the GAO to examine the LCCA practices.
	NCAT: Continue ALDOT's current policy until recommendations are made by the GAO study.	

Table 6.2 Analysis Period Recommendations

Guidance	Recommendations	Discussion
FHWA - "Analysis Periods should be long enough to capture long-term differences in discounted life-cycle costs among competing alternatives." A minimum of 35 years is recommended, but shorter periods may be appropriate to simplify some computations.	UA Team: 50 years	• ALDOT records show average serviceable life of concrete pavement at time of removal/rubblization is 32 years. • The analysis period of 35 years is long enough to capture the rehabilitation costs of both pavement types and the costs of concrete pavement removal/rubblization at the end of its lifespan. • Longer periods of time increase the uncertainty of many LCCA inputs as shown with ALDOT traffic forecasts. • New design procedures give pavement engineers the "ability" to design pavements with longer performance periods. However, those designs have not been proven with real performance data.
	NCAT: 35 years	

Table 6.3 Performance Period Recommendations

Guidance	Recommendations	Discussion
FHWA - Agencies determine specific performance information for pavement strategies through analysis of pavement management data and historical experience.	UA Team: N/A NCAT: <u>Asphalt</u> Initial Const.: 19 yrs. Rehab.: 13.5 yrs. <u>Concrete</u> Removal/In-place Demolition: < 35 yrs.	• Current initial construction performance data from ALDOT PMS is scarce. • NCAT Test Track performance shows current asphalt technologies far exceed the design lives. • ALDOT Pvmt. Mgmt. Office analysis indicates performance periods of asphalt overlays average 13.4 years. • National studies show asphalt overlays last approximately 19 years for interstate type thresholds based on the IRI.

Table 6.4 Agency Costs Recommendations

Guidance	Recommendations	Discussion
FHWA – Agencies gather appropriate and *current* cost data for the construction, maintenance, and other costs relevant to the alternatives under consideration. LCCA needs to consider differential costs between alternatives.	UA Team: Include admin., engineering, and construction mgmt. costs of rehabs. NCAT: Costs are determined based on weighted average winning bid data from the past twelve months of ALDOT lettings. Further research is needed to determine fair values of engineering and construction management costs for LCCA.	• ALDOT has a good process for using representative cost data for asphalt pavements in LCCA. • Due to limited data for concrete pavements in AL, historical data may need to include projects from two or more years. When this is the case, the historical bid prices should be adjusted to current costs by applying an inflation factor. • When the pavement choice affects other significant aspects of the project, such as adjusting bridges, drainage structures, and traffic control plan, those differential costs must be included in the LCCA. The case of the concrete project on I-59 in Etowah County is a good example. That project required extensive adjustments to drainage systems, signage, slopes, and bridges. An asphalt option would have required much less up-front engineering and project management effort. • Besides joint sealing, ALDOT should include commonly used concrete rehabilitation activities, such as slab replacement, diamond grinding, and under-sealing, and asphalt overlays. Ignoring these rehabilitation activities is an unfair advantage to concrete pavements in LCCA.

Table 6.5 Discount Rate Recommendations

Guidance	Recommendations	Discussion
FHWA - "discount rates should be consistent with OMB (The White House Office of Management and Budget) Circular A-94…" and "should reflect historical trends over long periods of time…" "*Real* discount rates reflect the time value of money with no inflation premium and should be used with non-inflated dollar cost estimates of future investments."	UA Team: annual OMB 30-yr. real discount rate NCAT: Rolling 10-yr. avg. of OMB 30-yr. real discount rate.	• The current 30-yr. Treasury Bill interest rate used by OMB is at an all-time historic low of 2.0%. • A rolling average of the OMB published discount rate evens out annual fluctuations over a longer period of time that is appropriate for long-term investment decisions.

Table 6.6 Material Specific Inflation Rate Recommendations

Guidance	Recommendations	Discussion
OMB SEP 2012 Memo - Regardless of any assumptions about relative prices and costs, all alternatives being compared should be discounted with the same discount rate following the guidelines in Section 9 of Circular A-94.	UA Team: Recommends using escalated costs, which are essentially material specific inflation rates. NCAT: Reject the use of material specific inflation or discount rates.	• Use of material specific inflation rates is not recommended by FHWA, OMB, or any other government authority. • Available data do not indicate that inflation rates for asphalt mixtures and concrete differ significantly over the past 10 to 20 years. • Attempting to predict specific commodity prices or even general inflation rates over any length of time is a foolish venture.

Table 6.7 Price Adjustment Clause (Indexing) Recommendations

Guidance	Recommendations	Discussion
AASHTO's 2009 Survey on State of Practice - 47 states use price adjustment clauses (PACs) on at least one construction input and more than 40 states reporting using PACs for both fuel and liquid asphalt	UA Team: Account for asphalt indexing in LCCA NCAT: Supports continued use asphalt indexing	• The two teams approached this issue differently. • NCAT's paper discussed the benefits of PACs, which include increased competition, lower bids, and necessary stability for smaller contractors. • UA's paper recommends a method for accounting asphalt indexing in the LCCA. However, it fails to address that the timing at which the "current" unit costs of the alternatives have to be adjusted to the same point in time before using this step, which would require both asphalt and concrete mixture adjustment factors. It also does not consider the use of RAP or recycled asphalt shingles, and does not use the current ALDOT price index procedure in the adjustment method.

Table 6.8 Salvage Value Recommendations

Guidance	Recommendations	Discussion
FHWA - the FHWA technical brief includes discussion of Residual Value and Remaining Service Life which suggests that one or the other be included in LCCA when the performance period extends beyond the Analysis Period.	UA Team: Salvage value should be based on remaining life of last rehab. only NCAT: LCCA should include demolition or removal cost for concrete, and salvage value for asphalt pavements	• At the end of the Analysis Period (35 years), concrete pavements have no remaining service life. Removal or in-place demolition has to be included in the LCCA. • Asphalt pavements can be resurfaced indefinitely. • The portion of the asphalt pavement remaining from initial construction has a value that must be included in LCCA. • The remaining life of the last overlay must also be converted to a salvage value.

Table 6.9 User Cost Recommendations

Guidance	Recommendations	Discussion
FHWA Economic Analysis Primer - Best-practice LCCA should reflect work zone user costs along with agency costs.	UA Team: N/A NCAT: Consider User Costs when NPVs of the alternatives are 10% of each other or if excessively long queues might form during rehabilitation	• If an agency cites benefits to users as a justification for spending agency dollars to build or rehabilitate a road, it should also recognize the costs to users caused by these actions. • Even if user costs are not counted on a dollar-to-dollar basis with agency costs, quantifying them through LCCA informs decision makers about the potential costs to road users. • Guidance given by the FHWA on calculating User Costs is straightforward. ALDOT can further simplify the procedure if needed.

Table 6.10 Pavement Design Recommendations

Guidance	Recommendations	Discussion
FHWA - supports States to develop implementation plan for the new Mechanistic-Empirical Pavement Design Guide (MEPDG) including input libraries, training, calibration studies, and validation projects.	UA Team: N/A NCAT: MEPDG is not ready for implementation. Local calibration is required.	• The models used in MEPDG development were based on limited data from existing pavements that were not built with current materials and construction technologies. • The program developers recommend "local calibration" of the models before implementation. • NCAT Test Track results show that MEPDG predictions are not accurate. Cracking model is bad.

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