Technical Report Documentation Page

1. Report No. FHWA/TX-09/0-6085-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CONSIDERATIONS FOR RIGID VS. FLEXIBLE PAVEMENT DESIGNS WHEN ALLOWED AS ALTERNATE BIDS: TECHNICAL REPORT		5. Report Date March 2009 Published: August 2009
		6. Performing Organization Code
7. Author(s) Andrew J. Wimsatt, Carlos M. Chang-Albitres, Paul E. Krugler, Tom Scullion, Tom J. Freeman, and Maria B.Valdovinos		8. Performing Organization Report No. Report 0-6085-1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Project 0-6085
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Technical Report: November 2007 – December 2008
		14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Considerations for Rigid vs. Flexible Pavement Designs When Allowed as Alternate Bids

URL: http://tti.tamu.edu/documents/0-6085-1.pdf

16. Abstract

This report documents the research conducted for the Texas Department of Transportation (TxDOT) concerning the use of pavement alternates. The scope of the project includes reviewing the state-of-the-practice in methods used for pavement type selection, interviewing TxDOT key personnel with experience in developing pavement structure alternatives, conducting a side-by-side comparison of current TxDOT pavement design methods, developing guidelines with a protocol for considering rigid versus flexible pavement designs when allowed alternate bids, and developing the Alternate Pavement Design Analysis Tool (APDAT) for pavement type analysis.

17. Key Words Flexible Pavement, Rigid Pavement, Life-Cycle Cost Analysis, Alternate Pavement Design Analysis Tool, APDAT, RealCost, Pavement Design, Pavement Type Selection, Alternate Bids		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 134	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

CONSIDERATIONS FOR RIGID VS. FLEXIBLE PAVEMENT DESIGNS WHEN ALLOWED AS ALTERNATE BIDS: TECHNICAL REPORT

by

Andrew J. Wimsatt, Ph.D., P.E.
Division Head
Materials and Pavements Division
Texas Transportation Institute

Carlos M. Chang-Albitres, Ph.D., P.E.
Assistant Professor
Department of Civil Engineering
The University of Texas at El Paso

Paul E. Krugler, P.E.
Research Engineer
Materials and Pavements Division
Texas Transportation Institute

Tom Scullion, P.E.
Senior Research Engineer
Materials and Pavements Division
Texas Transportation Institute

Tom J. Freeman
Engineering Research Associate
Materials and Pavements Division
Texas Transportation Institute

Maria B. Valdovinos
Graduate Research Assistant
Materials and Pavements Division
Texas Transportation Institute

Report 0-6085-1
Project 0-6085
Project Title: Considerations for Rigid vs. Flexible Pavement Designs
When Allowed as Alternate Bids

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

March 2009
Published: August 2009

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Andrew Wimsatt, P.E. #72270. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors thank the members of TxDOT's Project Monitoring Committee: Darlene Goehl, Hua Chen, Lizette Colbert, and Magdy Mikhail. Special thanks go to the project director, Duane Schwarz, and the program coordinator, German Claros, as well as those who participated in the interviews for this project. Special thanks to Nadarajah Sivaneswaran from the Federal Highway Administration for his continuous feedback during the development of this research. This project would not have been possible without the generous support, feedback, guidance, and assistance from all of these individuals.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1:
INTRODUCTION

This report documents the development of guidelines and a user friendly tool for considering alternate pavement designs, rigid and flexible, when allowed as alternate bids. The scope of the project included reviewing the current methods used by U.S. departments of transportation (DOTs) for pavement type selection, interviewing key personnel from the Texas Department of Transportation (TxDOT) to identify the data input needs and factors involved in the comparison of pavement designs and pavement type selection, conducting a side-by-side comparison of pavement designs using current TxDOT methods, preparing guidelines for analyzing pavement structure alternatives, and developing the Alternate Pavement Design Analysis Tool (APDAT).

SIGNIFICANCE TO TXDOT

The use of pavement alternates should lead to significant savings for TxDOT if the alternates use equivalent pavement structures that meet TxDOT's performance standards over a specified period of service.

Alternate bids should attract more contractors, thus increasing competitiveness and hopefully resulting in lower construction costs. Potential savings to users are also expected.

However, there are situations where pavement alternates may not be the appropriate strategy. The findings from this research will hopefully assist project designers in determining when the use of pavement alternates would be appropriate.

ORGANIZATION OF THE REPORT

The introductory chapter includes a brief overview of the project, including its significance to TxDOT and a description of the organization of the report.

Chapter 2 describes the literature review conducted at the beginning of the project to identify key elements in the pavement type selection process that TxDOT should consider.

Chapter 3 includes a summary of the interviews with TxDOT personnel from different districts and divisions, in order to obtain more information and insights concerning pavement alternate designs.

Chapter 4 explains the side-by-side comparison using current TxDOT Pavement Design methods. This analysis was conducted to get additional insights about pavement design methods and to propose what adjustment factor(s), if any, should be considered for equivalent pavement alternate designs.

Chapter 5 presents guidelines, including a protocol, for determining when pavement alternates should be considered. The guidelines are supported by a user friendly tool (APDAT) to facilitate their implementation by TxDOT. It also suggests a modification to the TxDOT Design Summary Report (DSR) and recommends inputs for life-cycle cost analysis (LCCA).

Chapter 6 summarizes the findings and recommendations from this research project.

CHAPTER 2:

LITERATURE REVIEW FOR THE STATE-OF-PRACTICE IN METHODS USED FOR PAVEMENT TYPE SELECTION

The literature review mainly focuses on current methods used by U.S. departments of transportation for pavement type selection including the California Department of Transportation (Caltrans), Colorado Department of Transportation (CDOT), Kentucky Transportation Cabinet (KYTC), Louisiana Department of Transportation and Development (LADOTD), Missouri Department of Transportation (MoDOT), Pennsylvania Department of Transportation (PennDOT), South Carolina Department of Transportation (SCDOT), and Washington State Department of Transportation (WSDOT). Prior efforts conducted by the Texas Department of Transportation to provide guidelines for a pavement type selection process were also considered in the literature review. Top references from asphalt and concrete trade associations as well as selected items that were considered of interest for the project are included as background information in the introductory section of this chapter.

The purpose of the literature review was to identify key elements in the pavement type selection process that should be considered by TxDOT. A summary of the findings with recommendations are included at the end of the chapter.

BACKGROUND INFORMATION

For more than two decades, studies have been proposed to assist in selecting a pavement type that would best fit a project. Different approaches have been discussed, and there is really no consensus toward a standard methodology. In the past, the choice of the type of road pavement was made mostly on an improvised basis. In order to identify the most rational and scientific choice of the type of pavement, some typical designs were worked out for both rigid and flexible pavements based on standard practice and comparative cost studies; while working out the comparative costs, initial construction costs, strengthening and maintenance costs have been considered as key elements. The analysis also includes the cost of vehicle operation in some cases (*1*).

In 1985, an economic study conducted on South Africa recommended pavement types for heavy traffic of up to 75 million Equivalent Single Axle Loads (ESALs). The study concluded that the general policy followed by the National Transport Commission of specifying that 20 percent of the heavy-duty pavements should be concrete on top of a cement stabilized sub-base, and 20 percent should be asphalt surfacing on top of a bituminous base and a cement stabilized sub-base. The remainder may be of asphalt surfacing on top of a crushed-stone base and a cement stabilized sub-base. The conclusions were based on a present worth of cost comparisons. The study considered 30 years for the analysis period. Factors considered in the economic analysis for comparison of the pavement type included initial construction cost, the expected maintenance costs, road-user delay costs, and the expected salvage value at the end of the analysis period (*2*).

There are models used to estimate user costs, including vehicle operating costs. The World Bank developed the Highway Design and Standards Model (HDM) from data collected in Brazil from 1975 and 1984. The HDM model is a tool that can be used for feasibility studies and includes its own models to relate construction and maintenance standards to road geometry and pavement surface condition to user costs. Roughness is the principal road-related factor used in the models. Vehicle Operating Cost (VOC) models are embedded in HDM. Relations for predicting vehicle speed, fuel consumption, and tire wear are based on principles of vehicle mechanics. HDM was formulated for use in developing countries. It is not being used in the U.S., but it is a popular model used worldwide to estimate user costs *(3)*.

In 1996, Pittman stated that the U.S. Army Corps of Engineers' thickness design procedures for rigid and flexible pavements were deterministic in nature. The pavement design methods use only one value, typically the mean value, for each of the design parameters and essentially ignore the inherent variability of the design parameters during the design process. Variability in the design parameters, such as the California Bearing Ratio (CBR) of the subgrade in flexible pavement design, for example, should be taken into account. Pittman stated that the use of probabilistic techniques to address the variability of pavement design parameters through the consideration of the standard deviation or coefficient of variation (CV) into an estimated reliability for key parameters should be encouraged. This probabilistic approach would enable an engineer to evaluate the impact on pavement design due to the potential variability of the input values (*4*).

More recent studies conducted by the Asphalt and Concrete industry bring insights on how to apply LCCA methodology to compare pavement types. However, each industry defends the type of pavement of its preference.

Top References from Asphalt Associations

In 2004, the Asphalt Pavement Alliance (APA) released a position paper that concluded that pavement type selection should be a road user-oriented process, not an industry-oriented process. It states that the system used to select pavement type should be objective, defensible, understandable, and based on historical records, primarily driven by economics and periodically reviewed. APA supports the use of life-cycle cost analysis in the decision making process and recommends the methodology developed by the Federal Highway Administration (FHWA) in Demonstration Project 115. The Net Present Value (NPV) is used for the purpose of comparing alternatives. Initial costs, maintenance costs, and salvage value are recommended for consideration in the life-cycle cost analysis. APA recommends a 40-year analysis period when comparing asphalt with concrete pavements. APA states that asphalt pavements possess many advantages when compared with concrete pavements including low initial cost, low maintenance costs, flexibility and speed of construction, the ability to handle heavy loads, a long life, and complete recyclability (*5*).

Newcomb, in an article published in Centerline in 2004 with news from the Asphalt Pavement Association of Oregon, stated that primary factors affecting pavement type selection include traffic, soil characteristics, weather, and construction considerations. Newcomb stated that the pavement type selection process must be a rational process, based not only on financial costs but on facts concerning performance, cost of the pavement structure, speed and timing in construction, safety, and realistic maintenance and rehabilitation schedules. In his opinion, asphalt pavements offer specific advantages when compared with concrete pavements (*6*).

In 2005, APA presented a synthesis on pavement life-cycle cost studies using actual cost data. Analyses for existing pavements on interstate highways located in Kansas, Ohio, and Iowa were conducted to compare costs between hot mix asphalt (HMA) pavements and portland cement concrete (PCC) pavements. Life-cycle cost analysis was used for the comparison of pavement alternates using historical data from agency records. Pavement designs considered similar traffic and comparable age for the alternatives. The present worth costs over analysis periods ranging from 20 to 39 years were calculated. There is no mention of user costs in the analysis. Based on the study, APA shows that HMA pavements have lower costs than PCC pavements by 10 to 25 percent in both initial construction costs and life-cycle costs (*7*).

APA conducted another study in 2005 to determine the average service life of flexible pavements to reach an unacceptable surface condition. Researchers considered six types of distresses in the analysis including fatigue cracking, longitudinal cracking in the wheel path area, longitudinal cracking outside the wheel path area, transverse cracking, rut depth, and smoothness measured by the International Roughness Index (IRI). Data for the analysis were extracted from the Long-Term Pavement Performance (LTPP) database. The median age of the 643 sections considered in the study was 17 years with 109 sections that were older than 20 years. An analysis to determine the probability of failure was performed for each distress type. According to the study, the expected service life to a moderate distress level exceeds 20 years for all distresses (*8*).

The Asphalt Institute promotes SW-1, an asphalt pavement thickness design software that applies Mechanistic-Empirical principles to design flexible pavements. SW-1 is written in conformance with the Asphalt Institute MS-1, MS-11, MS-17, and MS-23 manuals (*9*).

Top References from Concrete Associations

The American Concrete Pavement Association (ACPA) states that concrete pavements are a better choice than asphalt pavements because they have advantages in several areas including safety, durability, smoothness, versatility, and value. On safety, it provides better visibility, reduced wet spray since concrete never ruts, and provides the best traction grip. On durability, concrete hardens over time, and outlasts flexible materials since their average life span is 30 years. On smoothness, concrete stays smoother longer, creating safer, comfortable transportation surfaces and saving fuel. On versatility, concrete pavements can be 1) designed to last from 10 to 50 years, 2) used to rehabilitate old asphalt pavement using white topping, or 3) used to rehabilitate a worn concrete pavement. On value, concrete pavements provide the best long-term value due to their longer life, they are easy to repair, and they can be built and opened to traffic in less than 12 hours (*10*).

In 2002, ACPA published a guide for comparing alternate pavement designs using LCCA. The guide describes the LCCA process factors that influence the results including agency costs (initial cost, maintenance and rehabilitation costs, salvage value), user costs (delay of-use costs, roadway deterioration costs, and accident crash cost), discount rate, selection of rehabilitation activities, use of comparable sections, and length of the analysis period. Present worth (PW) and the equivalent uniform annual cost (EUAC) are mentioned as economic indicators used to express LCCA results. APA recommends EUAC because all costs are expressed in terms of an annual cost over the analysis period. The guide also presents a brief summary of life-cycle cost and performance studies conducted with historical data in Michigan, Minnesota, Iowa, Florida, Tennessee, South Dakota, Utah, and Georgia. According to these studies, concrete sections lasted between 1.6 and 2.6 times longer than the asphalt sections and were from 14 percent to 250 percent more effective than the asphalt pavements (*11*).

ACPA recommends the use of a Windows™ Pavement Analysis Software (WinPAS™) to perform rigid pavement design. WinPAS incorporates the pavement design methods from the 1993 AASHTO Guide for Design of Pavement Structures. A life-cycle cost module is included in the software program to perform LCCA for different pavement alternates (*12*).

ACPA also promotes StreetPave, a software used to perform thickness design for streets and local roads. According to ACPA, the software optimizes concrete pavement thickness. It also incorporates an asphalt cross-section design process to create an equivalent asphalt pavement design. Cost/benefit analysis is supported through a life-cycle cost analysis module (*12*). However, the Asphalt Institute does not agree with the way ACPA applies their method to develop an "equivalent" asphalt pavement design. The Asphalt Institute claims that StreetPave inappropriately reduces the single subgrade modulus value that the user inputs prior to running the asphalt design calculation while no similar reduction is performed with the concrete design (*13*).

Top References from the U.S. Department of Transportation, Federal Highway Administration

In 1998, the Federal Highway Administration published an Interim Technical Bulletin with recommended procedures for conducting life-cycle cost analysis (LCCA) of pavements. The bulletin discusses how to address alternative pavement design strategies, length of performance periods and activity timing, agency costs (initial cost, maintenance and rehabilitation cost, residual value), and user costs (delay costs, vehicle operating, and crash cost) in LCCA. The Net Present Value is proposed as the economic indicator for comparing alternatives. The FHWA encourages risk analysis. A sensitivity analysis is recommended as a minimum to study the impact of the individual outputs on LCCA results. The discount rate is one of the major factors considered in the sensitivity analysis. The use of simulation techniques incorporated into LCCA, such as Monte Carlo, is recommended to account for the variability of the input values and their influence in the results of the analysis (*14*).

In 2002, the office of Asset Management at the FHWA published a Life-Cycle Cost Analysis Primer. The primer was intended to provide background information to evaluate infrastructure investment alternatives. The LCCA approach considers total user and agency costs when comparing alternatives. The application of Benefit Cost Analysis (BCA) to account for benefits in the comparison of alternatives is discussed in the primer. If expected benefits provided by the alternatives under comparison are different, then BCA is considered more appropriate than LCCA. A description of the LCCA process steps is included with a discussion on how to establish design alternatives, determine activity timing, estimate costs (agency and user), compute life-cycle costs, and analyze the results. The use of the equivalent uniform annual cost or the present value is recommended as economic indicators to compare alternatives. The primer mentions that LCCA can follow a deterministic or probabilistic approach to account for the level of risk and uncertainty in the input values (*15*).

In 2005, FHWA published a *Context Sensitive Roadway Surfacing Selection Guide.* It documents the available options for roadway surfacing, and provides a decision-making process to allow consideration of all conventional engineering design factors including structural capacity, performance, durability, safety, and life-cycle costs. It also considers aesthetics, context compatibility, and environmental impacts. The guide presents a review of Federal Lands Highway's (FLH) Project Delivery Process (PDP) and a roadway surfacing selection process that includes consideration of context sensitivity, to be used in conjunction with the PDP (*16*).

Models that apply economic analysis at the network management level use LCCA and BCA principles. The Highway Economic Requirements System (HERS) is a highway investment/performance model developed by the FHWA, which has been used since 1995 to compare alternative highway investment levels and program structures. HERS simulates highway condition and performance levels and identifies deficiencies in need of improvement through the use of engineering principles. Since alternatives under analysis may provide different benefits, the BCA is recommended. Highway investments needed to implement improvements and benefits are estimated. Benefits are the reductions in user costs, agency maintenance costs, and any others over the life of the improvement. HERS seeks the optimization of the relationship between public highway investment and user costs (*17*).

RealCost is a program developed in Microsoft Excel ™ by the FHWA to support LCCA at the project level. FHWA published the user manual in 2004 with the aim to encourage the use of LCCA nationwide to analyze project alternatives objectively and consistently. RealCost evaluates the cost effectiveness of alternative pavement designs for new roadways and existing roadways (*14*). It allows performing LCCA deterministic and probabilistic calculations following FHWA methodology. Default values used by RealCost are taken from the FHWA's Technical Bulletin published in 1998 (*14*). RealCost compares two alternatives at a time but the pavement engineer can compare an unlimited number of alternatives by saving input files of all alternatives under consideration. RealCost requires that the user enter agency costs and service lives for individual construction or rehabilitation services. However, it automates FHWA's work zone user-cost calculation method (*14*).

In November of 2008, Peter J. Stephanos, Director of the Office of Pavement Technology, issued a memorandum with clarifications of FHWA's policy for bidding alternate pavement type on the National Highway System. It states that "FHWA does not encourage the use of alternate bids to determine mainline pavement types primarily due to the difficulty in developing truly equivalent pavement designs." Equivalent design implies that each alternative will be designed to perform equally, and provide the same level of service, over the same performance period, and has similar life-cycle costs (*18*). The memorandum indicates a few factors that should be considered when the decision to bid alternate pavement types has been made. These factors include:

- commodity price adjustment factors;
- incentive/disincentive (I/D) provisions for quality;
- specifications of material quantities;
- SEP 14 approval needed if using adjustment factors: some states have used price adjustments to account for differences in life-cycle costs for the alternate pavement types to determine the lowest responsive bidder. Adjustment factors should include anticipated maintenance costs, anticipated rehabilitation costs, and salvage value (*18*); and
- approval requirements.

PAVEMENT TYPE SELECTION PRACTICES AT U.S. DEPARTMENTS OF TRANSPORTATION

California Department of Transportation

The California Department of Transportation published a *Life-Cycle Cost Analysis (LCCA) Procedures Manual* in November 2007. Caltrans plans to use this manual on pavement projects to evaluate alternative pavement designs for new and existing roads. The LCCA procedures recommended in the technical Bulletin published by the FHWA in 1998 are followed in the manual. LCCA begins with the selection of alternative pavement designs to accomplish the same performance objectives. When comparing a flexible and a rigid pavement alternate, the same design life should be used. However, Caltrans recommends the comparison of pavement alternates with different design lives for the same type of pavement. The intention is to determine during the Project Initiation Document (PID) phase which alternate pavement design life is the most cost effective. Pavement design alternatives for a 10-year, 20-year, and 40-year pavement design life are compared using a discount rate of 4 percent. Caltrans chose RealCost, which is a computer program developed by the FHWA, to facilitate the numerical calculations. Instructions and examples on how to use RealCost are provided in the LCCA procedures manual. RealCost can be used to perform deterministic and probabilistic LCCA. It is highlighted in the manual that probability functions for individual input variables are under development for Caltrans. Therefore, Caltrans only uses the deterministic approach at this time (*19*).

Colorado Department of Transportation

The Colorado Department of Transportation published a report in 2006 that explains the use of LCCA to support pavement type selection; in particular for projects that had initial construction pavement costs over one million dollars. CDOT recommends a 40-year analysis period when comparing flexible to rigid pavements. This report describes agency and user costs. Agency costs include all costs incurred by the agency during the life of the project. User costs are the costs incurred by the highway user and may include time delay costs, vehicle operating costs, accident costs, discomfort costs, and environmental costs. Work zone user costs are considered by CDOT and calculated for LCCA using a software program called “WorkZone.” The CDOT report describes how to use LCCA following a deterministic and a probabilistic approach. CDOT historically used a discount rate of 4 percent for LCCA deterministic calculations. A method to use discount rate and inflation rate in LCCA probabilistic calculations is presented in the report. Two URL address are provided to obtain data for the analysis. A histogram is built with these data. For the discount rate the link is http://www.forecasts.org/data/data/GS10.htm, and for the inflation rate the link is http://inflationdata.com/Inflation/Inflation_Rate/HistoricalInflation.aspx. CDOT considers a salvage value of zero for LCCA deterministic calculations but defines the probabilistic salvage as the "value between years used and rehabilitation life all divided by the rehabilitation life that total multiplied by the rehabilitation cost." The present value is the economic indicator used by CDOT to compare alternatives. When a probabilistic LCCA is conducted, CDOT used a 75 percent level of risk in the analysis (*20*).

Kentucky Transportation Cabinet (KYTC)

In January of 2006, the KYTC published a document that superseded their original Pavement Type Selection Policy. Primary engineering factors that are to be considered and documented in all pavement type selection reports include: traffic; soils characteristics; construction considerations; cost comparison, including initial cost analysis and life-cycle cost analysis; design life; analysis period; rehabilitation cycles and strategies; agency and user costs; salvage value; unit cost and discount rate. Secondary engineering factors are also considered and documented in all pavement type selection reports once the primary factors are found to be equivalent. These include: performance of similar pavements in the area, adjacent existing pavements, district maintenance capabilities, incorporation of experimental features, and stimulation of competition (*21*).

In projects where the primary and secondary factors are determined to be equivalent for both pavement types, alternate pavement bidding is sometimes considered.

When alternate pavement bidding is used to determine pavement type, the KYTC uses a bid adjustment in the bidding process to determine the successful bidder. The bid adjustment value will be determined based on the future agency costs as calculated in the life-cycle cost analysis. The actual value will be the net present value of the future agency costs calculated based on a 4 percent discount rate. The actual bidding procedure will add the bid adjustment value for either the asphalt or the concrete alternate to the bid of the contractor bidding the respective alternate. The bid adjustment value will only be used to determine the low bidder and will not be used to determine final payment to the contractor.

The following formulas will be used for alternate bidding:

Total Bid (Concrete Bidder) = $A + C_{concrete}$

Total Bid (Asphalt Bidder) = $A + C_{asphalt}$

Where,

A = dollar amount for all work to be performed under the contract and

C = Bid Adjustment Value for the respective pavement alternate.

When alternate bidding is used on a project and the user costs during initial construction are calculated to be greater than $2,000,000 for either alternate, a time component may be added for bidding purposes. The "B" component will be added to allow contractors to bid the number of calendar days necessary to complete all work associated with a project. The value of the "B" component will be calculated using the procedures outlined in FHWA-SA-98-079 "Life-Cycle Cost Analysis in Pavement Design (*14*)." The daily work-zone costs should be determined based on the maintenance of traffic strategy specified in the plans or proposal.

The following formula will be used for alternate bidding with a time component:

Total Bid = A + B + C

Where,

A = dollar amount for all work to be performed under the contract,

B = number of calendar days necessary to complete all work

(The number of days will be multiplied by the daily user cost), and

C = the Bid Adjustment Value for the respective pavement alternate.

Louisiana Department of Transportation and Development (LADOTD)

LADOTD developed a process that allows selection of pavement type through the bid process. The core element in this policy is the alternate design, alternate bid (ADAB) procedure that uses life-cycle cost analysis to estimate the long-term costs. The A component is the contractor's base bid, and the B component is the time-based bidding. Construction costs, future costs of maintenance and rehabilitation, traffic control, and user delay costs are considered in the analysis when comparing asphalt and concrete pavements. If there is a difference of 20 percent in life-cycle costs it is considered that pavement design can compete and be considered for pavement type selection through the bidding process. The objective of implementing this procedure is to allow industry to participate in the selection of the pavement type through the bid process (*22*). LADOTD follows the LCCA methodology recommended by FHWA in its interim technical bulletin (*14*). Traffic, construction duration, and costs are updated continuously. Activity timing considered by LADOTD for future rehabilitation is indicated in Table 1.

Table 1. Activity Timing Considered by LADOTD for Future Rehabilitation (*22*).

Project Type	Alternate	Year 0	Year 15	Year 20	Year 30
Interstate Overlay	Rigid	New Bonded PCC Overlay	No Action	Clean / Seal Joints 3 Patches per mile	None
	Flexible	New Asphalt Concrete Overlay	Cold Plane and Overlay	No Action	None
Interstate New Construction	Rigid	New Joint Portland Concrete Pavement	No Action	Clean / Seal Joints Patch 1 percent of Joints	Retexture Patch 3 percent of Joints
	Flexible	New AC Pavement	Cold Plane and Overlay	No Action	Cold Plane and Overlay
Other Arterial New Construction	Rigid	New JPC Pavement	No Action	Clean / Seal Joints Patch 1 percent of Joints	Retexture Patch 2 percent of Joints
	Flexible	New AC Pavement	Cold Plane and Overlay	No Action	Cold Plane and Overlay

User delay costs are also included in the LCCA but only work-zone costs that result from construction and future rehabilitation are estimated. A factor C is added to the ADAB model used in Louisiana, where C represents the user delay costs. The model is known as A+B+C in Louisiana. The A+B+C process was developed by an agency special committee and after consensus was presented to industry. It is considered that the 20 percent threshold value serves to discard low-volume roads from the alternate pavement type selection process since traffic volume and load are low for pavement systems to compete. According to LADOTD, implementation of ADAB appears to have reduced contract bid prices (*22*).

LADOTD uses LCC adjustment factor(s) to obtain representative values over a year for design use. Among them are the daily adjustment factors that account for variation of traffic within a week and the seasonal adjustment factors that account for the variation of traffic among different months. These are derived from present value of future costs; they include agency and user costs (*22*).

Missouri Department of Transportation

The Missouri Department of Transportation published a report in 2004 to document the history of pavement design and type selection process. Initial efforts to implement a pavement type selection process go back to 1998. The report proposes future enhancements to the process based on prior experience and feedback from industry. MoDOT's pavement type selection process considers truck traffic and subgrade to select a range of design thicknesses for pavement types under comparison. The four primary types of pavement design in Missouri include full-depth hot mix asphalt , conventional HMA overlay, jointed plain concrete pavement (JPCP), and unbonded JPCP overlay (*23*).

The performance standard selected by MoDOT is the International Roughness Index that is considered universal to all pavement types. Table 2 shows the recommended IRI for Missouri's use in the pavement type selection process.

Table 2. Recommended IRI (inches/mile) Performance Ranges (*23*).

Good	**Improvement not required**		
	IRI	Interstate	< 95
		Other	< 95
Fair	May need improvement in near future		
	IRI	Interstate	95 – 120
		Other	95 – 170
Poor	Improvement required		
	IRI	Interstate	> 120
		Other	> 170

To compare pavement designs MoDOT adopted the Mechanistic-Empirical (M-E) Design Guide upon its completion. A life-cycle cost analysis is run on selected pavement types with heavy emphasis on construction costs. A 35-year design period is recommended. Table 3 shows existing 35-year LCCA design period treatments used by MoDOT. However, it was considered that design periods could be extended beyond 35 years based on higher design life expectations with improved PCC and HMA pavements. Other states, as shown in Table 4, consider pavement design periods over 35 years (*23*).

Table 3. Existing 35-year LCCA Design Period Treatments Used by MoDOT (*23*).

Initial Treatment	1st Rehabilitation Treatment	1st Rehabilitation Time	2nd Rehabilitation Treatment	2nd Rehabilitation Time
New Full-depth HMA	Cold mill and replace travelway HMA wearing surface	Year 15	Cold mill and replace entire HMA wearing surface	Year 25
New JPCP	Diamond Grinding (and 2 percent full depth repairs)	Year 25	None	None
Conventional HMA Overlay	Cold mill and replace travelway HMA wearing surface	Year 15	Cold mill and replace entire HMA wearing surface	Year 25
Unbounded JPCP Overlay	Diamond Grinding (and 2 percent full depth repairs)	Year 25	None	None

Table 4. Other States' Extended Design Life Expectations (*23*).

State	Design Period (yrs)	Rehabilitation Treatments within Design Period	
		HMA	PCC
Illinois	40	4 – mill and HMA overlay (3 w/additional structure for 4.5" total)	6 – full depth patching operations for 15 percent total 1 – diamond grinding
Iowa	40	1 – mill and HMA overlay w/1" additional structure	No major rehabilitation
Minnesota	50	3 – mill and HMA overlay	1 – minor concrete pavement restoration (CPR) 1 – major CPR w/ diamond grinding
Nebraska	50	2 – mill and HMA overlay adding ~ 4" structure each time	1 – diamond grinding 1 – HMA overlay
Wisconsin	50	3 – mill and HMA overlay	1 – diamond grinding 1 – HMA overlay

MoDOT uses a cost analysis spreadsheet to estimate the cost-effective pavement type — either flexible or rigid for a specific project. Since the analysis is based on average anticipated future supplier costs it may not reflect material and construction costs at the time the project is bid. User costs are not currently calculated into the pavement type selection process. MoDOT considers that allowing alternate bids on pavements contributes to achieving the lowest cost for the longest life. Figure 1 shows the overall pavement type selection process recommended by MoDOT (*23*).

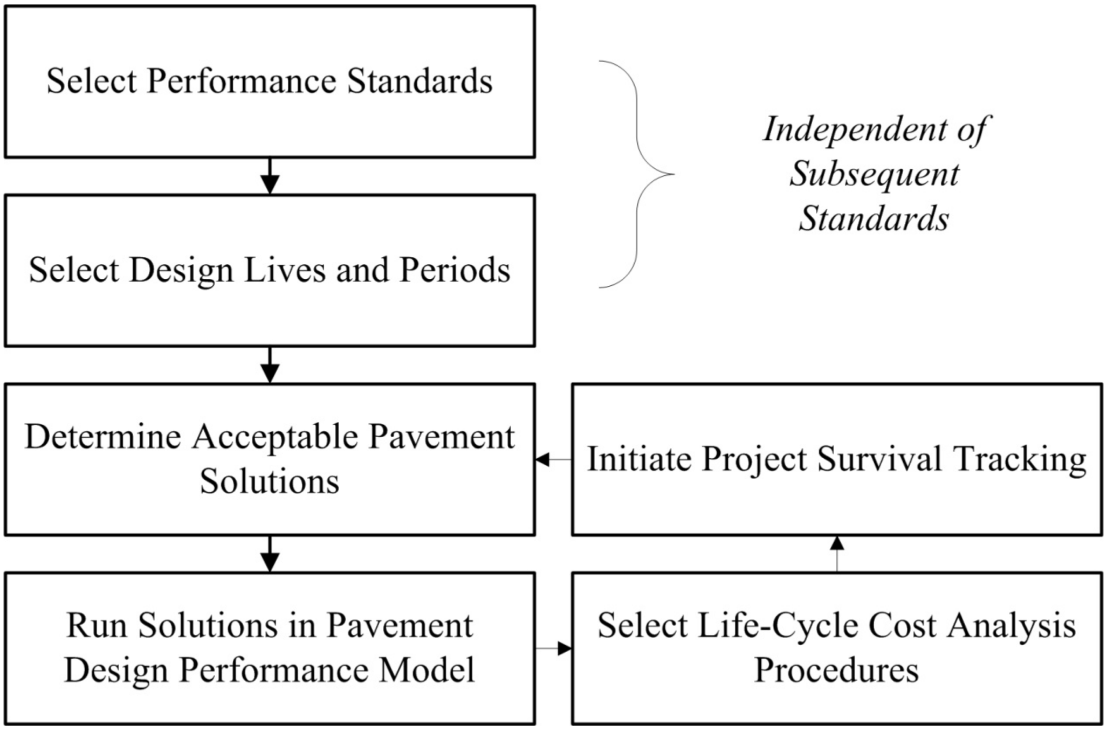


Figure 1. Pavement Type Selection Process Recommended by MoDOT (*23*).

To ensure that every effort is being made to increase the competition for paving contracts, and that the latest market rate is considered when determining pavement type, contractors are allowed to bid an alternate pavement design. Maintenance costs are considered with a life-cycle cost adjustment factor, thus resulting in the most equivalent specifications possible to draw in the maximum number of bidders for MoDOT paving projects. While alternate bidding is generally advantageous for all projects, circumstances occasionally arise that cause one pavement type to be preferred over the other (*24*).

Following this line of thought, and to determine whether an alternate pavement project qualifies for a life-cycle cost adjustment factor or is let as an “optional” pavement project with no factor, the total area of pavement is analyzed.

Life-Cycle Cost Adjustment

For alternate pavements a life-cycle cost adjustment factor is added to the lowest asphalt bid to consider the future rehabilitation cost for each pavement type. This life-cycle cost adjustment factor considers future cold milling and overlay of the surface layer of asphalt at 20- and 33-year intervals and diamond grinding of the concrete surface at 25 years. The last published real interest rates from the United States Office of Management and Budget is used to bring the future costs to present worth. The MoDOT Design Division calculates the cost adjustment factor utilizing the most updated information available. Two separate LCCA factors are calculated for the contract, one for the mainline pavement and one for the shoulder pavement (5 ¾ in or thicker). This will allow contractors flexibility in bidding, thus enabling use of the best value material for the regional market. Projects with alternate pavements will include a life-cycle cost adjustment factor as calculated by the Design Division or a $0 life-cycle cost adjustment factor according to Table 5 below (*24*).

Table 5. Use of Life-Cycle Cost Adjustment Factor for Alternate Pavements (*24*).

Area of Pavement and Shoulder *	**> 14,000 yd^2 total**	**< 14,000 yd^2 total**	
		≥ 7,500 yd^2 Continuous	**≤ 7,500 yd^2 Continuous**
LCCA?	Yes	Yes	No (Let as “Optional”)

* Includes A2 (5 ¾ in.) or thicker shoulders

According to an independent peer review done by the Transtec Group, Inc. about MoDOT’s Pavement Design and Type Selection Process, reduced prices for both asphalt and concrete have been shown in the years 2002 to 2006 when alternate bids were employed. This result suggests that increased competition has actually led to lower prices.

Pennsylvania Department of Transportation

The Pennsylvania Department of Transportation recommends LCCA to select pavement types. The procedure described in the FHWA’s Interim Technical Bulletin on LCCA published in 1998 (*14*) was adopted. PennDOT pavement design selection guidelines require comparison of flexible with concrete pavements using LCCA over a 40-year analysis period. Pavement design alternatives should meet the performance requirements through the analysis period. Initial construction cost and future rehabilitation and maintenance costs are considered in the analysis. Work zone user costs are also calculated to address additional delay and vehicle operating costs due to effects of work zones on roadway capacity. A discount rate of 6 percent is taken into account for the LCCA calculations. The need for data to conduct LCCA is emphasized. At first, the PennDOT LCCA used expert opinion to overcome the absence of a historical database to extract these input data needed for the analysis (*25*).

South Carolina Department of Transportation

The South Carolina Department of Transportation describes a pavement selection process in engineering directive memorandum 15. The pavement type selection proposed by SCDOT is based on the AASHTO structural number (SN). SCDOT takes asphalt pavements as the default selection when this number is below 4.5. For structural numbers between 4.5 and 6.0 the design engineer may also choose either asphalt or Portland Cement Concrete. If the analysis indicates that concrete pavement may be preferable, the pavement design engineer needs to consult a Pavement Advisory Committee. If the structural number is 6.0 or greater, the pavement design engineer needs to consult the Pavement Advisory Committee. The Pavement Advisory Committee consists of the materials and research engineer and permanent representatives from Maintenance, Construction, Traffic Engineering, and FHWA (*26*).

Factors that affect the pavement type selection include: construction considerations, initial costs, adjacent existing pavement, stimulation of competition, ease of maintenance, local preference, and recognition of local industry. Comparison of alternate structural designs, as well as cost estimates (initial construction costs and future costs), are recommended. User costs are not mentioned in the memorandum (*26*).

Figure 2 shows the SCDOT pavement type selection process.

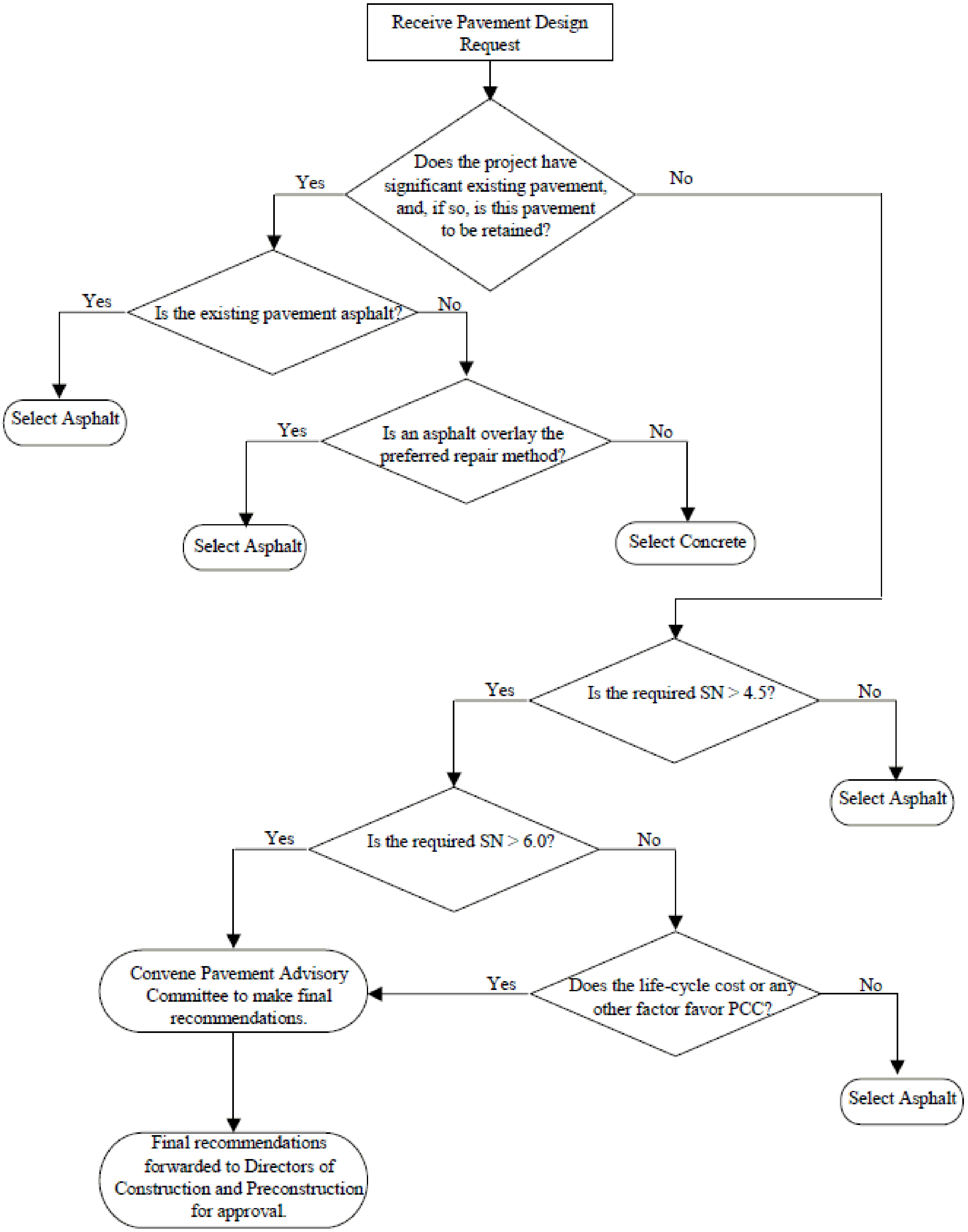


Figure 2. Pavement Type Selection Process Flow Used by SCDOT (*26*).

Clemson University for the South Carolina Department of Transportation

In April of 2008, Clemson University published the findings from a research investigation conducted for the SCDOT to evaluate LCCA practices among state highway agencies for pavement type selection. The research was based on analysis of data obtained from a survey of states across the U.S. and provinces in Canada. The survey estimated the level of LCCA that each state takes for a pavement type selection. Based on the analysis, a probabilistic LCCA approach was proposed for use with pavement type selection process in South Carolina. The publication also recommended a range of values for input parameters based on the survey data (*27*).

The study also found that RealCost was widely used by several state agencies and is most comprehensive in its treatment of different input parameters. FHWA has been actively involved in providing support to customize the software to meet individual state's needs. Therefore, the study proposed RealCost as the preferred software for use when conducting a LCCA during pavement type selection (*27*).

In the following paragraphs, the preliminary and final survey results are mentioned, as well as the principal findings published in the report.

Preliminary Survey Results and Analysis

A total of 33 states and two Canadian Provinces responded to the web-based preliminary survey. Ninety-four percent of the agencies indicated that they use LCCA as part of the decision process for selecting a pavement type. Figure 3 shows the states that responded to the survey.

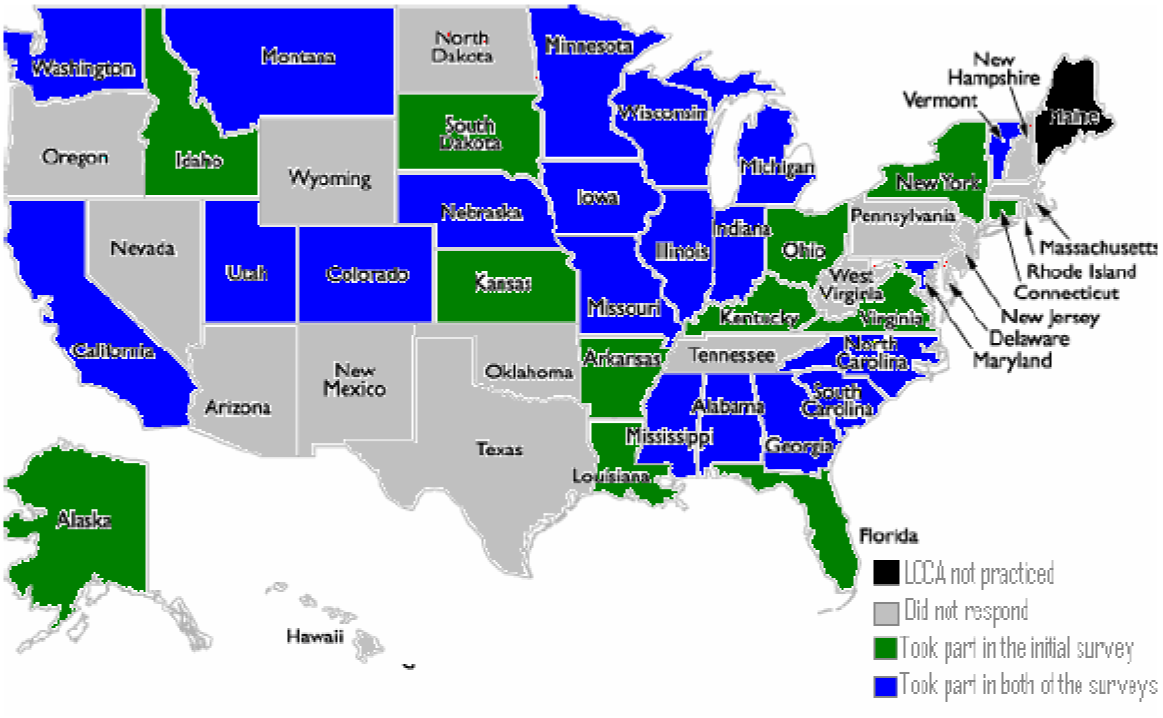
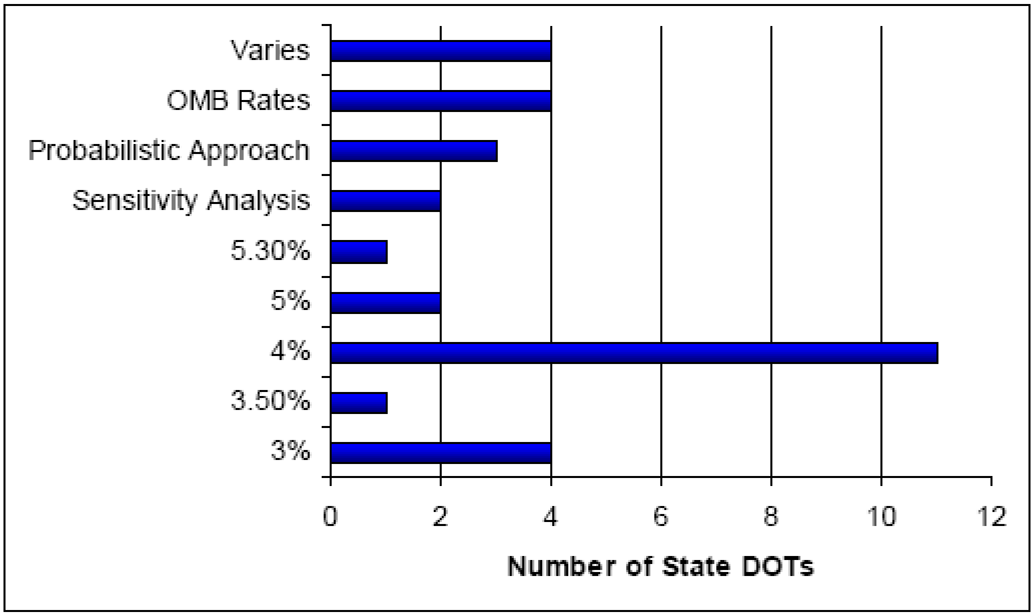


Figure 3. Geographical Representation of Responses in the 2-stage LCCA Survey (*27*).

When asked about the inclusion of user costs in their analysis, about 60 percent of the states (19 out of 32) said that they do not consider user costs in LCCA calculations. Three of these states said they plan to include them in the future. Most of the DOTs that include user costs in the analysis, calculate only user delay costs during construction and major rehabilitation activities (*27*).

According to the survey, almost 6 percent of the respondents (2 out of 32 states) conduct sensitivity analysis of their discount rates. Figure 4 shows the number of states that use certain discount rates.



OMB: Office of Management and Budget

Figure 4. Discount Rates Used by DOTs in Most Recent Projects as of 2005 (*27*).

When asked about maintenance and rehabilitation, some agencies reported that they do not differentiate between the two and include both costs in the analysis. But, apparently most agencies do not include maintenance costs in their LCCA. The distinction between the two is not very clear, and they seemed to vary from agency to agency. What one agency considers maintenance, another agency considers rehabilitation.

Forty-four percent of the states that responded to this preliminary survey indicated that they do not consider salvage value in their calculations. Fifty-three percent of the states include salvage valued in their LCCA process, and one of the DOTs includes it in a probabilistic analysis (*27*).

Finally, the agencies were to report any guidelines or policies they have regarding their LCCA procedures. Seventy-five percent of the states indicated that they have guidelines, and the rest of them did not have guidelines or policies for LCCA. Two of these agencies indicated that their guidelines were being developed.

Final Survey Results and Analysis

A final survey was prepared and e-mailed to state transportation officials that responded to the preliminary survey. The objective of this final survey was to gather more specific information about the approaches that each state is taking for pavement type selection process. A total of 24 agencies responded to this survey. Ninety-two percent of these (22 agencies) use LCCA for pavement type selection. Two of the respondents, Maine and British Columbia, indicated that they do not use LCCA since they only have flexible pavements (*27*).

Sixty-eight percent of the 22 states that use LCCA indicated that they are satisfied with their existing LCCA process or had minor concerns. The other 32 percent have specific concerns about their current LCCA practices. Fifty-nine percent of the responding states are considering revisions to the LCCA process in order to achieve a more realistic comparison between pavement alternates (*27*).

A very important aspect that was analyzed during the survey was the factor or factors that trigger LCCA. Figure 5 shows the results of the survey indicating that cost of the project was the most selected criteria.

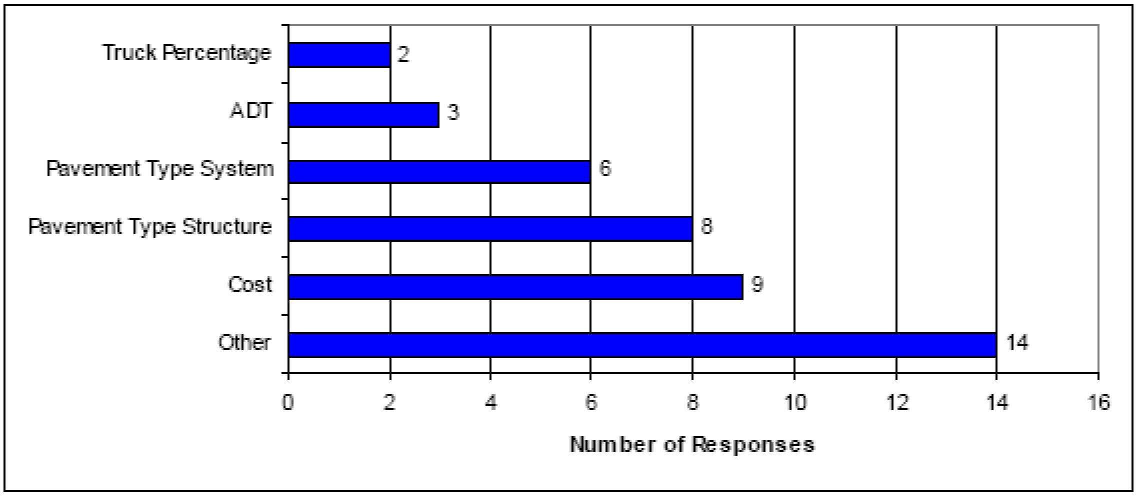


Figure 5. Criteria That Trigger the Requirement to Conduct LCCA (*27*).

In the year 2006, four years after the release of RealCost, only one state was using a probabilistic approach for all projects. About 81 percent (17 out of 21) of the agencies still used a deterministic approach, and 14 percent used a combination of both. Figure 6 shows the number of agencies using the different approaches.

Twenty-five percent of the State Highway Agencies (SHAs) indicated the use of a sensitivity analysis on several parameters to deal with the uncertainty in LCCA. Some of the parameters considered in this sensitivity analysis are discount rate, analysis period, timing of rehabilitation, and unit costs of materials.

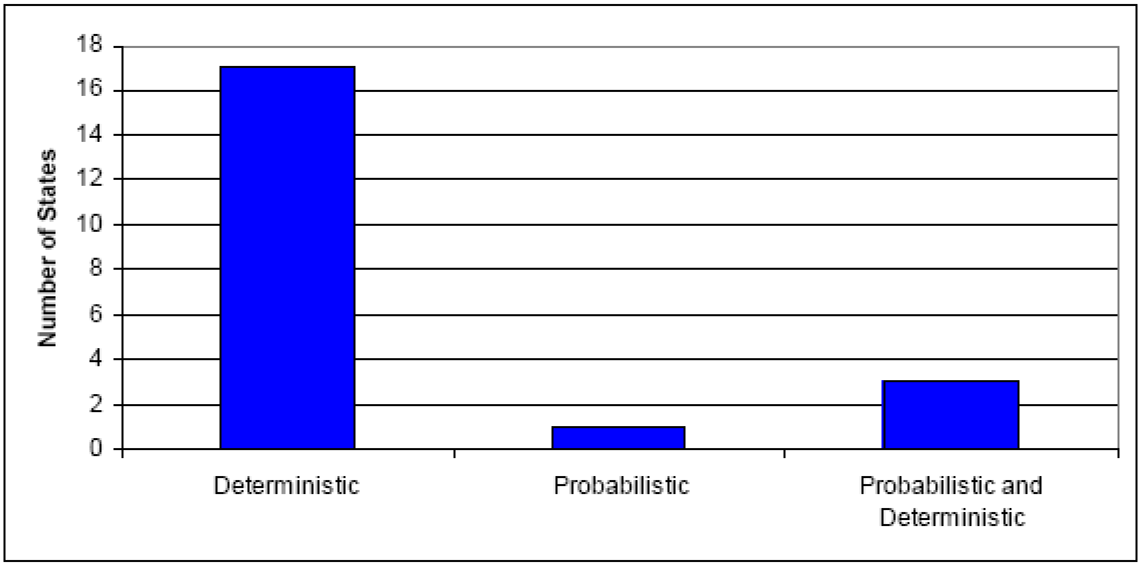


Figure 6. Number of States Using Different Approaches in Their LCCA (27).

Figure 7 shows the number of state DOTs that use different sources of the data for input parameters when conducting LCCA.

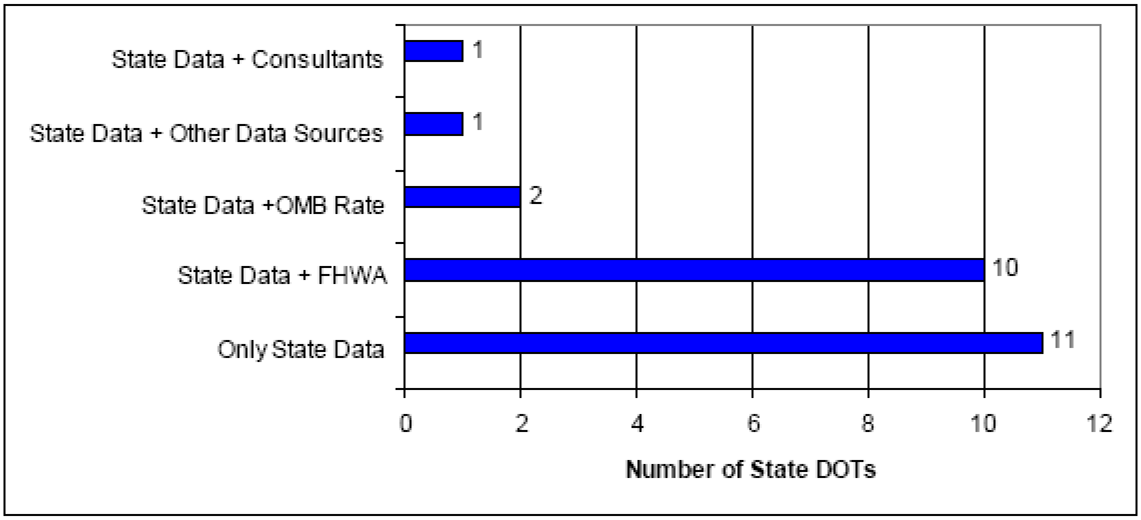


Figure 7. Data Sources Used in Selecting the Input Parameters (27).

Table 6 summarizes the responses for different states on the performance life of initial pavement design, the life of subsequent rehabilitation activities for both flexible and rigid pavements.

Table 6. Analysis Period and Rehabilitation Timings (*27*).

State DOT	Analysis Period	Time to First Rehabilitation (years)		Rehabilitation Service Life	
		Flexible Pavements	Rigid Pavements	Flexible Pavements	Rigid Pavements
Alabama	28 years	12 years	20, type not a consideration	8 years	8 years
California	20 to 55 years	18-20 years Preventive maintenance before	JPCP[1] 20 – 40 Preventive maintenance before	10 years	At least 10 years
Colorado	40 years	10 years	JPCP – 22 years	10 years	18 years
Georgia	40 years	10 years	CRCP[2] – 25 years JPCP – 20 years	10 years	20 years
Illinois	40 years	Depends on traffic	CPR[3] of JPCP at 20 years CRCP: constructed for high volume traffic routes and no LCCA[4]	Depends on the traffic factor	20 years
Indiana	40 years	25 years	JPCP – 30	15 years	12 years
Kansas	30 but moving to 40 years	10 years	JPCP – 20	Approximately 10	7 – 10 years
Maryland	40 years	15 years	JPCP – 20 Based on a 2-year initial structural life	12 years	Varies depending on which rehabilitation cycle
Michigan	Depends on the pavement/type	26 years	JPCP – 26 years	10 – 15 years	21 for unbonded overlay, 20 for rubblizing & OL
Minnesota	50 years	For 7 million ESAL or less, route and seal cracks at year 6, for high ESALs do a crack fill at year 7.	JPCP – 17 years	Depends on traffic	1st rehabilitation: Joint reseal & minor CPR that lasts 10 years. 2nd rehabilitation: partial & some full depth repairs to last 13 years 3rd rehabilitation: major CPR to last 15 years (gives a 33 percent residual life at the end of the analysis period)
Massachusetts	40 years	12 years	JPCP, 1st rehabilitation at 16 years	9 years	16
Missouri	45 years	20 years	25 years	13 years for 1st mill and OL, 12 years for 2nd mill and OL	20
Montana	35 years	19 years	JPCP, 20 years	12	20
Nebraska	50 years	15-20 years	OL[5] at 35 years unless performing exceptional	4" OL for 12 – 15 years, additional 4" OL for a total life of 5 years.	15 for a total life or 50 yrs

[1]JPCP – Jointed Plain Concrete Pavement, [2]CRCP – Continuously Reinforced Concrete Pavement, [3]CPR – Concrete Pavement Rehabilitation, [4]LCCA – Life-Cycle Cost Analysis, [5]OL – Overlay, [6]OGSC – Open Graded Surface Course,[7]DBR – Dowel Bar Retrofit, [8]HMA – Hot Mix Asphalt, [9]SMA – Stone Matrix Asphalt.

Table 6. Analysis Period and Rehabilitation Timings (*27*) (Continued).

State DOT	Analysis Period	Time to First Rehabilitation (years)		Rehabilitation Service Life	
		Flexible Pavements	Rigid Pavements	Flexible Pavements	Rigid Pavements
North Carolina	20 years for SN<6 & 30 years for SN>6, looking at 40 years for SN>6	12 – 15 years	JPCP, 15 years	12 years	10 years
South Carolina	30 years	12 years for conventional mixes, 15 years for polymer-modified	JPCP, 20 years	10 for conventional, 15 for polymer modified	10 years
Utah	-	12 – 15 years	JPCP, 10 years for minor, 20 for major	OGSC[6] is at 7 to 8 years, rest is variable	Varies
Vermont	-	Varies	20 years	10 – 12 years	10 – 15 years
Washington	50 years	10 – 17 years	JPCP 20 – 30 years	10 – 17 years	Diamond grinds 15 – 20 years, DBR[7]15 years
Wisconsin	50 years	18 years over dense graded base & 23 years over open graded base	25 years (undrained base) if placed over dense graded base & 31 years if over open graded base	Mill & OL to give 12 years of service life	8 if the initial rehab is repair 15 if the initial rehab is HMA[8] OL
Ontario	50 years	19 years for dense friction course, 21 years for SMA[9]	JPCP, 18 years to first rehab, which is a minor CPR & diamond grinding	13 years, then 12 years, then 11 years, then 10 years	10 years

[1]JPCP – Jointed Plain Concrete Pavement, [2]CRCP – Continuously Reinforced Concrete Pavement, [3]CPR – Concrete Pavement Rehabilitation, [4]LCCA – Life-Cycle Cost Analysis, [5]OL – Overlay, [6]OGSC – Open Graded Surface Course, [7]DBR – Dowel Bar Retrofit, [8]HMA – Hot Mix Asphalt, [9]SMA – Stone Matrix Asphalt.

Table 7 shows the parameters used by each state to arrive at user costs. As may be seen, only eight states responded, five of which provided values for the different parameters. Based on the agencies' responses, it is obvious that only a few states have adopted the user costs in estimating the LCCA for pavement type selection.

Table 7. Parameters Used to Arrive at User Costs (*27*).

Parameters	**States**							
AADT construction year (total for both directions)	**CA**	**CO**	**GA**	**IN**	**MI**	**UT**	**VT**	**WA**
Cars as percentage of AADT (percent)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Single unit trucks as percentage of AADT (percent)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Combination trucks as percentage of AADT (percent)	Yes	Yes	Yes	Yes	All trucks lumped together	Yes	Yes	Yes
Annual Growth rate of traffic (percent)	Yes	Yes	Yes	Yes		Yes	Yes	Yes
Speed limit under normal operating conditions (mph)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lanes opened in each direction under normal operating conditions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Free flow capacity (vehicles per hour per lane)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Queue dissipation capacity (vphpl)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Maximum AADT (total for both directions)	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Maximum queue length (miles)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Rural or urban hourly traffic distribution	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 8 summarizes the responses regarding the use of salvage value in the LCCA. Out of the 23 state DOTs that answered, 10 said they always include salvage value in their calculation, eight of which only include serviceable life in the analysis.

Table 8. Usage of Salvage Value (*27*).

State	Yes	No
Alabama		X
California	X	
Colorado	No for deterministic, Yes for RealCost	
Georgia	X	
Illinois		X
Indiana	X	
Iowa		X
Kansas		X
Maryland	X	
Michigan		X
Minnesota	X	
Mississippi		X
Missouri		X
Montana	X	
Nebraska	X	
North Carolina		X
South Carolina		X
Utah		X
Vermont		X
Washington	X	
Wisconsin	X	
British Columbia		X
Ontario	X	

Summary of Principal Findings and Recommendations (27)

Some of the conclusions published are cited below:

- About 92 percent of the survey respondents use LCCA for pavement type selection.
- Cost, pavement structure, and network level of the pavement in the system (interstate, secondary roads, etc.) were reported by many states to be the major criteria that would trigger the requirement to conduct LCCA.
- Over 50 percent of the responding agencies use RealCost, DARwin, or some other customized software to conduct LCCA.
- Approximately 60 percent of the states do not consider any type of user cost in their approach to LCCA. The states that do incorporate user costs, consider only work-zone user delay costs.
- Most of the states use a discount rate of 4 percent. Approximately 15 percent of the respondents address the uncertainty in the discount rate by using a range of values, between 3 and 5.3 percent.
- About 56 percent of the respondents include salvage value in their analysis. Eighty percent of these respondents calculate only remaining serviceable life, and the rest calculate both residual value and remaining serviceable life.

Based on the analysis, the following recommendations were made:

- A probabilistic LCCA approach was proposed for use with pavement type selection process in South Carolina.
- RealCost was proposed as the preferred software for use when conducting a LCCA for pavement type selection.
- Use the discount rates published in the OMB circular as the mean value, with +/– 1 percent as the minimum and maximum boundaries for the probabilistic approach.
- Use only remaining service life value of the pavement at the end of the analysis period as the salvage value.

- The following two alternatives were proposed for user costs.
    a. First, calculate these from user-delay costs (calculated using the length and time of lane closures along the traffic volume and vehicle type data). Monetary value of time for different types of cars/trucks is established.
    b. Second, address excessive queues and user delays even if user costs are not included in total costs. The length of the work zone queue during rehabilitation or construction is needed.

Washington State Department of Transportation

The Washington State Department of Transportation published in 2005 a pavement type selection protocol. The protocol describes that the pavement type selection follows a three-step process: pavement design analysis, life-cycle cost analysis, and engineering analysis.

The first step includes a review of the subgrade competency, traffic analysis, materials, climate/drainage, environment, and construction considerations. If there is some reason to choose one pavement type instead of another, the process stops here.

The second step is to conduct life-cycle cost analysis including initial costs, maintenance and rehabilitation costs, salvage values and user costs. A deterministic and a probabilistic approach are described for conducting LCCA. The present value method is recommended as the economic method for LCCA. LCCA software developed by the FHWA, RealCost, is proposed for LCCA calculations. WSDOT recommends an analysis period of 50 years for interstates or principal arterials, and 20 years for minor arterial or major collector roadways.

The third step, engineering analysis, is conducted when there are two viable alternatives: flexible or rigid pavement that can be considered approximately equivalent (*28*). A flowchart to illustrate the pavement type selection process is shown in Figure 8.

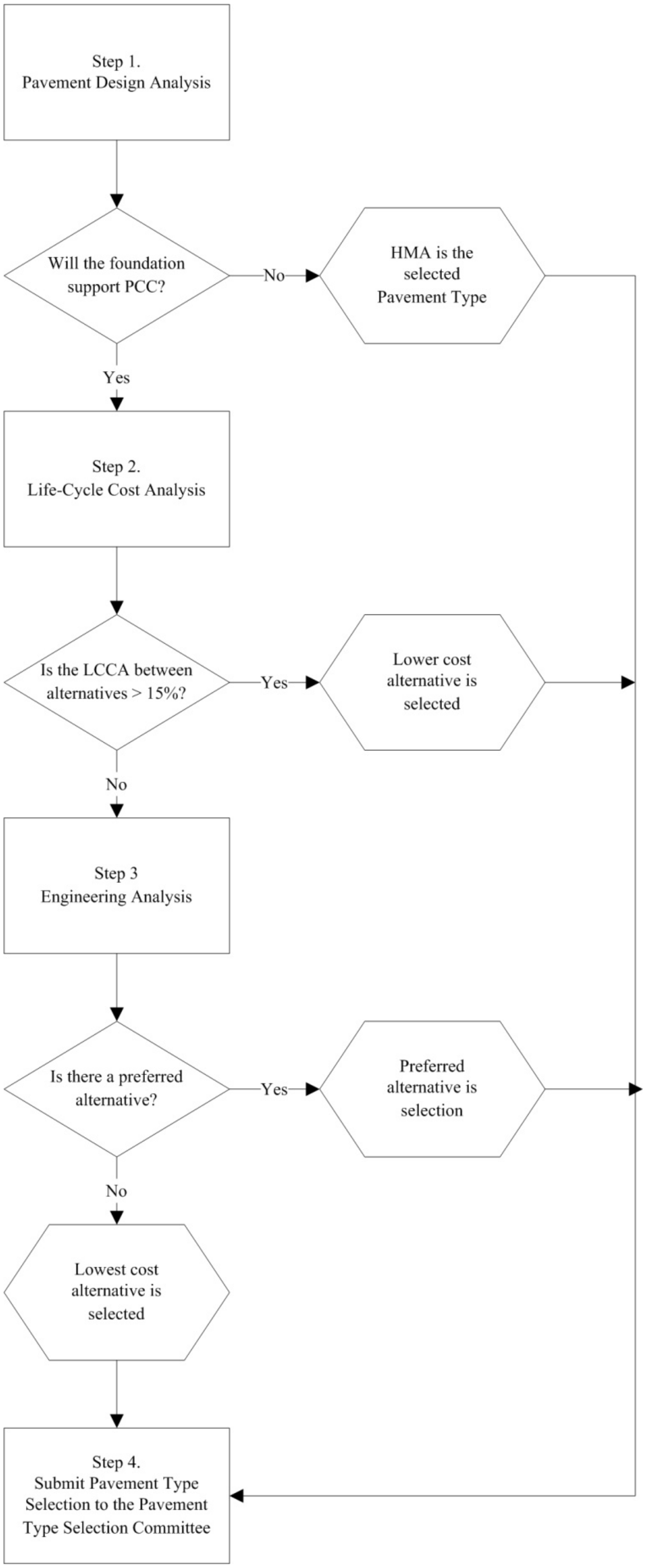


Figure 8. Pavement Type Selection Flowchart Used by the WSDOT (*28*).

PAVEMENT DESIGN AND PRIOR EFFORTS CONDUCTED BY TXDOT TO DEVELOP PAVEMENT TYPE SELECTION GUIDELINES

Many factors influence selection of the type of pavement to build. Some of the main factors include: traffic, soil characteristics, climate/weather, construction considerations, recycling, and cost comparison. There are also secondary factors such as: performance of similar pavements in the area, continuity of the cross section, conservation of materials and energy, availability of local materials, traffic safety, traffic noise mitigation, experimental features, and local preference.

The revised version of the TxDOT *Pavement Design Guide* was released in October 2006 (*29*). Three pavement design categories are distinguished in this guide: new pavement, pavement reconstruction, and pavement rehabilitation. There are three major types of pavements: flexible, rigid, or composite pavements. TxDOT uses both flexible and rigid pavement types. Flexible pavements are normally designed for a 20-year period, whereas rigid pavements are normally designed for a 30-year period. Flexible pavement structures are assumed to provide service within the first eight years of its life without requiring an overlay or major rehabilitation. Rigid pavements should not require major maintenance or rehabilitation during the 30-year period.

Flexible Pavement Design

Flexible pavements are frequently analyzed as a multilayer system under loads. Typically, a flexible pavement consists of a surface layer with an underlying base and sub-base. Each of the layers contributes to the structural support and drainage of the pavement, but when hot mix asphalt is used as the surface course, it usually contributes the most to pavement strength, since it is the stiffest (high resilient modulus) layer. There is a special type of flexible pavement called “Perpetual Pavement” that uses premium HMA mixtures to obtain a long-life structure that can support heavier traffic loads. This type of pavement can last up to 30 years or more if it is maintained properly. The typical section for a perpetual pavement has a thickness of about 20 inches total (*29*).

FPS-19W software is used to assist in flexible pavement design. FPS-19W is a mechanistic-empirical design method. The first version of this method, FPS-11, was developed in the 1970s. A mechanistic design check is used in FPS-19W, in which traditional fatigue and rutting prediction models are used to estimate the number of load repetitions to failure. In addition, critical stresses, strains, and deflections are computed by FPS-19W using the WESLEA linear-elastic analysis to verify whether the pavement structure will be able to withstand the expected traffic loads or will fail due to rutting or fatigue. Design parameters are input into the program including the length of the analysis period, serviceability index, and design confidence level. Traffic data, environmental (temperature), and subgrade conditions (swelling probability, potential vertical rise, and swelling rate) are entered. Construction and maintenance data are also taken into account (time interval and overlay). Pavement and subgrade layer stiffness values (elastic moduli) back calculated from Falling Weight Deflectometer (FWD) and Poisson ratios are used to characterize materials. For the hot mix asphalt layer, the elastic moduli is corrected to 77° F. TxDOT districts are encouraged to develop their local set of elastic moduli values for the surface and asphalt materials. Default values are used by FPS-19W in the absence of specific district data (*30*). If heavy loads are expected during the design life, the pavement structure should be checked with the Modified Triaxial Design Method (*29*).

Rigid Pavement Design

Rigid pavements are analyzed using the plate theory. These pavements have a structure composed of hydraulic cement concrete surface course with an underlying base and sometimes a sub-base course. The surface layer is the stiffest of all the layers. This layer is a concrete slab that provides the majority of the strength to the pavement. In order to reduce thermal stresses or eliminate joints and maintain tight crack widths, these types of pavements commonly use reinforcing steel. The following are types of rigid pavements: continuously reinforced concrete pavement (CRCP), concrete pavement contraction design (CPCD) or jointed concrete pavement, jointed reinforced concrete pavement (JRCP), post-tensioned concrete pavements, and composite pavement (*29*).

For rigid pavement design, the TxDOT Guide recommends the use of DARWin, a computer software product that provides users with tools for pavement design analysis (*29*). It uses the procedure in the 1993 AASHTO *Guide for Design of Pavement Structures* (*31*). It can actually be used for flexible and rigid pavement design. For flexible pavement design, DARWin allows the calculation of layer thickness by three user-selected methods, including an optimization scheme. The AASHTO rigid pavement design method is enhanced by the addition of the steel design equations for JRCP and CRCP and by the inclusion of in-depth guidance on many of the inputs to the rigid pavement design equation. The overlay design module incorporates the revised approach to pavement overlay design developed under NCHRP Project 20-7. The overlay design module provides a fully automated means of performing all of the different overlay design calculations, including automated FWD file processing and back calculation (*32*).

Mechanistic-Empirical (M-E) Design Guide, NCHRP 1-37A

The Mechanistic-Empirical Design Guide and the M-E computational software involve comprehensive pavement design procedures. A trial pavement structure, proposed by the designer, is evaluated using the M-E procedure for adequacy of expected performance over the service life. Pavement performance response models used by the M-E software are based on pavement properties and major distress/transfer functions. These performance models are used to predict states of stress, strain, and displacement within the pavement structure due to traffic loads and environmental conditions (*33*). To calibrate these models, data regarding material properties, pavement structural characteristics, traffic information, environmental condition, and performance are required. These data need to address the specific conditions of the region where the pavement structure is going to serve. Therefore, calibration and validation of the performance models is a critical issue for a successful pavement design. This M-E design guide is currently under consideration for implementation at TxDOT.

Functional and structural performance models are embedded into the M-E software. Fatigue cracking and rutting models are considered for structural performance, while riding comfort or ride quality for functional performance. For functional performance, the International Roughness Index is chosen as the standard measure.

The M-E guide provides great flexibility in design inputs. A three-level hierarchical design input approach is adopted in the M-E guide. The selection of the design input level depends on the criticality of the project and available resources. Level 1 input data are the highest level of accuracy, and it is recommended for designing heavily trafficked pavements. It also involves laboratory or field testing (dynamic modulus, site-specific axle load spectra) of the actual materials to be used. Level 2 input data are an intermediate level used when resources are not available for conducting the tests required for level 1; instead inputs are gathered from an agency database or a limited testing program using correlations. Level 3 input data are the lowest level of accuracy, and it is used when the consequences of early failure are minimal. Typical regional average values are considered sufficient for this pavement design level (*33*).

A number of input datasets are required for the M-E pavement design procedure. These datasets must cover: (1) pavement structural characteristics, (2) material properties, (3) traffic information, and (4) climate conditions. In addition to these four datasets, a performance dataset is needed for calibrating the M-E procedure. These datasets need a repository system to store the data so a database management system is required to handle the data stored in this repository system. TxDOT is working toward the assimilation of the M-E design guide into its own procedures. Research projects are currently being conducted to develop reliable data from selected pavement sections to calibrate pavement design and rehabilitation methods for Texas conditions. However, databases are not complete enough to conduct a full M-E design according to the NCHRP 1-37A guide (*33*).

TxDOT Pavement Related Databases

Accurate information is needed in order to adequately design a pavement. This information often includes: traffic loads, serviceability index, reliability, material characterization, drainage characteristics, and evaluating existing pavement conditions. The following databases are available and might be used for this project.

Pavement Management Information System (PMIS)

The Pavement Management Information System database is an automated system used by TxDOT for "storing, retrieving, analyzing, and reporting information to help with pavement-related decision-making processes." It contains information from 1993 to present. Location (example: reference markers, roadbed ID), pavement type and characteristics, pavement distress from visual surveys, climatic data (example: average annual rainfall), traffic data (example: ESALs, percent of trucks), and cross section data (example: layer thickness, last seal coat) are stored in this database. These data are used for planning, highway design, maintenance and rehabilitation, evaluations, and research (*34*).

Maintenance Management Information System (MMIS)

The Maintenance Management Information System stores maintenance data based on the Texas Reference Marker system. Location data and maintenance data (example: amount spent, type of work) are stored in this database. MMIS is well populated, and it is mainly used as a tool to produce state agency reports (*35*). The TxDOT PMIS imports pavement related maintenance expenditure data from MMIS. These costs are displayed in certain PMIS reports.

SiteManager Database

SiteManager is a comprehensive construction management system sponsored by AASHTO, departments of transportation, one Canadian Province, and FHWA. SiteManager is a relational object-oriented database that automates administrative functions currently handled manually for construction projects. Test results, inspector diaries, and material gradations are examples of the information that can be stored in SiteManager. Data stored in SiteManager include location data, material descriptions, material gradations, mix designs (contract mix, aggregate blend, bituminous concrete mixes, aggregate mix design, and pavement structural data), Hveem mix properties, Marshall Mix description, Marshall Mix properties, Superpave mix description, Superpave mix properties, bituminous materials, bituminous gradations, aggregate mix description, aggregate mix materials, aggregate mix gradation, pavement structural design data, aggregate blend data, specifications, and materials test results (*36*).

Design and Construction Information System (DCIS)

The Design and Construction Information System is an automated information system used for planning, programming, and developing projects. There are four modules in DCIS: project information, work program, project estimate, and contract letting. Most of the information stored in this database is useful for contract management since it has report tools to follow up the work progress and to control the stream of expenses on allocated resources. Another use is to estimate construction costs to assist in project evaluation (*37*).

Rigid and Flexible Pavement Databases

The rigid and flexible pavement databases are currently managed by the Center for Transportation Research at the University of Texas at Austin under TxDOT sponsored research projects 0-5445, “Project Level Performance Database for Rigid Pavements in Texas,” 0-5513, “Development of a Flexible Pavements Database,” and 0-6275, “Continued Development and Analysis of the Flexible Pavements Databases.” The researchers for this project thought that the information in both databases could be of use in this study. However, the Flexible Pavement Database is still under development. In addition, researchers are in the process of developing a web-based method for accessing the data in the Rigid Pavement Database. “A Database for Successful Pavement Sections in Texas” was developed under research project 0-5472 (*38*). This project ended on August 31, 2007, and made available information through a web-based interface about flexible pavements that have been identified by the Texas Department of Transportation as superior performers compared to similar pavement structures carrying similar traffic loads. Analyses of available construction records for these pavements and the results of pavement testing performed during this project are provided in the database. The web page address for this database is http://tsfp.tamu.edu/.

TxDOT Research Project 0-1734

In 1998, TxDOT conducted research project 0-1734 to develop a decision framework for making project-level pavement type selection decisions. Life-cycle cost analysis and cost-effectiveness analysis are used for economic comparison of alternatives. The trade-off between the following three major factors is evaluated in order to make a better choice as to which type of pavement to construct: agency costs, user delay costs, and performance levels (*39*). Figure 9 shows the framework proposed for the TxDOT pavement type selection process.

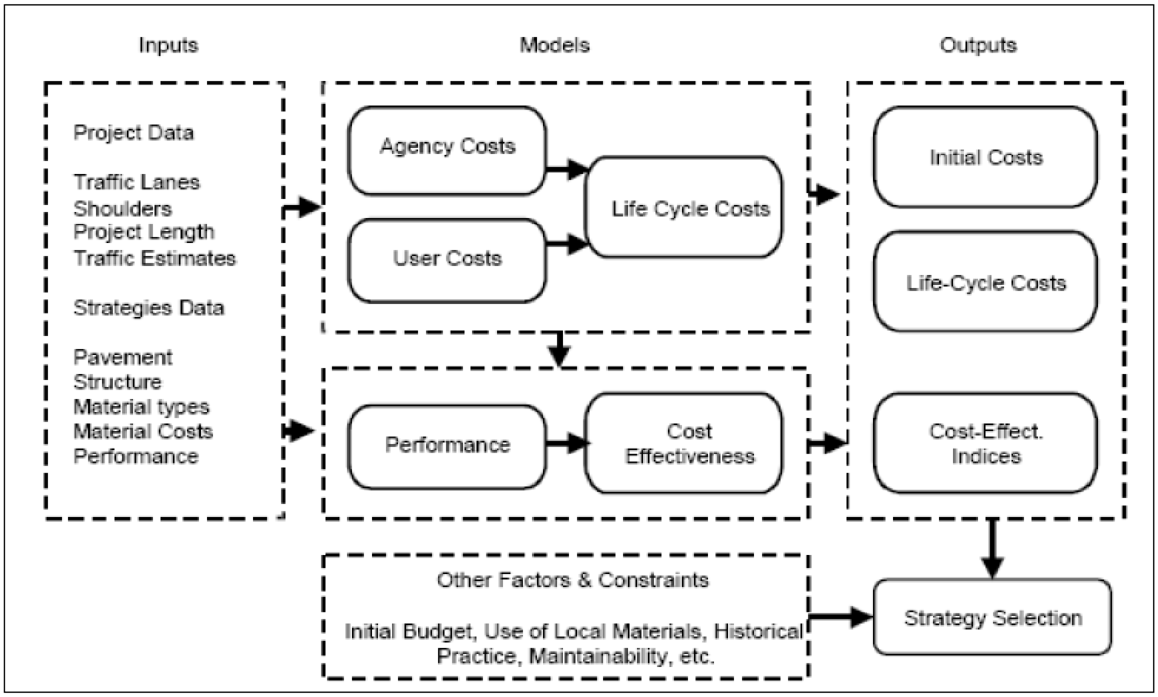


Figure 9. Framework for the Proposed TxDOT Pavement Type Decision Process (*39*).

The Present Serviceability Index (PSI) is used to set up performance levels over the period of analysis. One of the advantages of this method is that the use of an economic-based pavement type selection procedure improved the pavement selection decisions at TxDOT. The factors used to compare candidate strategies include economic indicators such as the initial cost of the project, the agency life-cycle cost, the total life-cycle cost, and the cost-effectiveness index.

A computer program called "Texas Pavement Type Selection (TxPTS)" was developed in this research as well and is discussed in detail later in the chapter. Vehicle operating costs (VOCs) are not used in this program, since previous studies show that the effects of VOC are more significant in the comparison of projects of paved versus unpaved roads (*39*).

The Texas Pavement Type Selection Program

Written in a Microsoft Visual Basic version 5.0, this program was developed to automate the economic evaluation of candidate strategies. It features four primary windows used for input data and another window used for output calculations and ranking and printing options. The four windows are:

- Project Information data: project description, district, county, highway, control begin, control end, length of project, number of lanes, lane and shoulder widths, and traffic direction.
- Flexible and Rigid Pavement Strategies data: the user will provide data about analysis period/life-cycle and annual routine maintenance cost, including initial construction and future maintenance and rehabilitation activities.
- Delay Cost data: Average daily traffic (ADT), truck percentage, annual traffic growth, lane capacity, work zone length, unrestricted approach speed, capacity speed, unite day cost for cars and truck, directional distribution, open lanes through work zones, work zone posted speed, hours or work zone operations, and hourly traffic distribution.
- Outputs and Ranking window: this window lets the user calculate the outputs, which include initial agency cost, life-cycle agency cost, total life-cycle cost, cost-effectiveness ratio based on agency LCCA, and the cost-effectiveness ratio based on total LCCA.

A Microsoft Access file is used to store the data input and output results. The program imports a default input file each time the new project option is selected. The user can interactively edit the inputs and perform analysis. The user can add the required number of candidate-flexible and rigid pavement strategies for the project (*39*). However, TxDOT has not implemented TxPTS.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

There is no consensus on what procedure to follow in a pavement type selection process (PTSP). Many DOTs including Caltrans, CDOT, LADOTD, MoDOT, PennDOT, SCDOT, and WSDOT have developed their own procedures and guidelines to support PTSP. These guidelines emphasize the importance of including life-cycle cost analysis in the PTSP. Although data input needs for LCCA are known and the process is very well described in documents published by the FHWA, the application of LCCA in each state depends on the availability of data and their own local construction, maintenance, and rehabilitation practices.

The Interim Technical Bulletin published by the FHWA in 1998 (*14*) is considered the major source of reference for LCCA. Differences in the application of LCCA methodology arise from the definition of the length of the analysis period, timing for maintenance and rehabilitation, estimate of the salvage value, and the incorporation or not of user costs into the analysis.

The recommended length of the analysis period for LCCA varies from 30 to 50 years depending on the pavement design. Maintenance and rehabilitation strategies are defined based on the state's construction practices. Some procedures considered zero as a salvage value while others provide a definition to account for this parameter in the LCCA. User costs, if considered in LCCA, are estimated based on the work-zone user cost approach that accounts for user time delays and indirectly impact on vehicle operating costs due to the presence of work zones.

LCCA can follow a deterministic or probabilistic approach. It is reported that the LCCA deterministic approach is currently in use due to data limitations to develop probability functions for individual input variables. However, tools are available for LCCA probabilistic calculations if reliable data exist to validate the probability functions. None of the states mention the existence of probability functions validated for the state. However, the states recognize the importance of a LCCA probabilistic approach to provide additional insights about the effects of input values on the outputs. A LCCA probabilistic approach will provide to the decision maker a sense of the level of risk of the design due to the uncertainty inherent in the input variables used in the analysis.

The Present Value is the preferred economic indicator for comparing alternatives. Recommended discount rates when a deterministic approach is used varies from 4 to 6 percent. Some procedures also considered the influence of inflation in LCCA.

RealCost, a software developed by the FHWA, appears to be the most current tool used by the states to assist in LCCA. Caltrans and WSDOT explicitly mention RealCost in their procedures as a powerful tool to facilitate LCCA.

An interesting mechanism to allow the selection of pavement type through the bid process has been implemented by LADOTD. It is called the alternate design, alternate bid procedure, and it is based on LCCA. A threshold value of 20 percent in life-cycle costs difference between alternate pavement designs is used to decide if the pavement type selection should be through the bidding process. It appears that ADAB has been accepted by the asphalt and the concrete industry since representatives from both industries provided feedback during its development.

The general consensus among the states is that allowing alternate bids on pavements should contribute to achieving the lowest cost for the longest life. The following recommendations should be considered in a procedure for TxDOT:

a. The ADAB procedure developed by LADOTD that proposes a threshold value to allow selection of the pavement type through the bidding process appears to have acceptance by both industries. The procedure deserves further thought to see if it can be incorporated into the pavement type selection process that will be developed for TxDOT.
b. Data inputs needed for pavement type selection analysis should be collected from TxDOT's existing records.
c. TxDOT's best construction practices should be considered when comparing alternative pavement structures. Maintenance and rehabilitation strategies considered in LCCA should match TxDOT's policies and be based on pavement performance observed in the field.
d. There is a need for a tool to support the pavement alternate process. The process for TxDOT should consider the use of Life-Cycle Cost Analysis. The Texas Pavement Type Selection Program developed by TxDOT in 1998 supports LCCA analysis but it has not been updated since then. RealCost is the software developed in Microsoft Excel™ by the FHWA to conduct LCCA. RealCost has been recently adopted by other states to facilitate LCCA, and it is the most current tool available for this purpose.

CHAPTER 3:
SUMMARY OF INTERVIEWS WITH TEXAS DEPARTMENT OF TRANSPORTATION PERSONNEL

In order to obtain more information and insight concerning pavement alternative designs, the research team interviewed TxDOT personnel in the Waco District, San Antonio District, Fort Worth District, Construction Division, and Design Division. The purpose of the interviews was to gain an understanding of the issues faced by TxDOT personnel in generating alternative designs and to document the current approaches to overcoming these issues. This chapter summarizes the findings from the interviews.

WACO DISTRICT

The Waco District let a project on IH 35 in Bell County that utilized pavement alternates; the contractor chose the rigid pavement design on that project. District personnel have also developed plans, specifications, and estimates (PS&E) using pavement alternates for roadways sections on SH 31 in McLennan County and US 190 in Temple (Bell County); however, these projects had not been let. District personnel decided to utilize alternates at the time for the 60 percent plan review for the recent projects; however, in the future, they intend to make a decision earlier in the process, such as at the time for the 30 percent plan review or earlier (i.e., when the pavement design is prepared).

The designers did not prepare life-cycle cost analyses for these projects. Instead, the designers computed initial construction costs for the alternates and determined that the prices were reasonably close, so they concluded that the projects were candidates for alternates. The district personnel interviewed for this research indicated that they considered the estimates reasonably close if they were within 10 to 15 percent of each other. They also suggested the following criteria to determine if a project should use alternates: (a) a minimum project cost of \$15 million to \$20 million, and (b) a minimum truck traffic value equal to 25 to 30 percent of the total current average daily traffic. If the above criteria are used, district personnel believed that local availability of contractors would not be an issue; and projects that have few bridges and no utility issues would most likely attract more bidders.

The designers used FPS-19W for the flexible pavement designs and the 1993 AASHTO Guide rigid pavement design procedure (*31*). District personnel did believe that the design needed to provide similar service performances; issues involving expansive soils and sulfate bearing soils also needed to be addressed. For IH 35, the designers used a 30-year analysis period with a time to first overlay of 14 years for the flexible (perpetual) pavement design and a lane distribution factor of 70 percent (since the project consisted of three lanes in each direction). For the SH 31 and US 190 projects, the designers specified a time to first overlay of 30 years (generally, for other projects, the Waco District uses a minimum time to first overlay of 8 years, but they have observed actual service lives of such overlays between 12 to 15 years). CRCP was used as the rigid pavement alternate for all three projects and was designed for 30 years; however, district personnel may consider using Jointed Concrete Pavement where intersections and frontage roads are involved. The Waco District's usual maximum depth of lime treatment for clays soils is 18 inches.

The personnel interviewed also indicated that for projects along a roadway that will be built in sections (i.e., in separate construction projects), the pavement alternate for the first project should be used on all future projects on that roadway. In addition, district personnel indicated that pavement alternates have not been considered in urban areas where sewer and water lines exist; the personnel indicated that they probably would not want to use a concrete section if there are utility maintenance issues that would require the pavement structure to be removed.

The Waco District has used lane rental charges for construction projects and may consider contracts using A+B (construction cost plus construction time) bidding in the future for projects using pavement alternates. District personnel also mentioned that traffic control for flexible pavement construction would be considerably different than for rigid pavement construction. District personnel indicated that perpetual pavements usually require several different mix designs with different binders that the contractor may have to consider when choosing the alternate. On the other hand, removing pavement markings on concrete pavement may leave "scars" that would not necessarily occur on HMA surfaces, especially if an overlay is involved.

District personnel believed that there was a lower bid on the IH 35 project because the plans contained pavement alternates. They have not received any negative comments from contractors concerning the use of pavement alternates on that project, probably since the selected concrete section required 4 inches of HMA as a sub-base, which meant that there was work for asphalt contractors, and the earthwork contractors would have work to conduct no matter what alternate was used.

Finally, district personnel indicated that more research was needed in applying life-cycle cost analyses in a realistic fashion for such projects.

FORT WORTH DISTRICT

As of March 2008, the Fort Worth District has let only one project using pavement alternates. It is located on SH 114 in Wise County (let in 2003). In 1997, the Texas Hot Mix Asphalt Paving Association (now known as the Texas Asphalt Pavement Association, or TxAPA) approached the district about constructing a full depth ACP perpetual pavement adjacent to a continuously reinforced concrete pavement in the eastbound direction of SH 114 in Wise County. The district agreed; and the sections were constructed and opened to traffic in 2005. The district also developed pavement alternates (full-depth ACP perpetual pavement using FPS-19W and CRCP using the AASHTO procedure) and included them in the plans for the westbound direction of SH 114. The contractor chose the ACP option in the westbound direction. The perpetual pavement designs used Superpave specifications.

During construction of the perpetual pavement in the eastbound direction, district personnel discovered that the Superpave layers were permeable. As a result, the district executed a change order with the contractor to install under-drains and to place a seal coat on the full depth ACP pavement before placement of the SMA surface. This did prevent any further moisture intrusion and resulting damage according to district personnel. However, the district realizes that the under-drains will need to be maintained and the seal coat replaced when the SMA is removed in the future.

As a result of the experience with the permeability of the full depth ACP structure, the district did change the design in the westbound direction to CRCP (again through executing another change order with the contractor).

The SH 114 project consisted of only one bridge, and the alternates in the westbound direction had the same total pavement thickness. This simplified developing the pavement alternates for the project.

Fort Worth District personnel also mentioned an issue when developing the estimates under TxDOT's Design Construction Information System mainframe application. When developing alternate designs, the estimates for each alternate have to be exactly the same dollar value to the nearest penny. The district would desire that the DCIS have more flexibility when generating estimates for alternates.

One interviewee indicated that consideration should be given to use pavement alternates for projects that may be relatively short in length since unit costs tend to be higher on such projects. Also, in the case where, for example, a roadway will be constructed or reconstructed in sections, the interviewee recommended using the same pavement structure for all sections.

District personnel indicated that local availability of contractors is not an issue in their area, and subgrade issues should be handled in the design. In addition, district personnel would probably not use concrete design where utility maintenance issues are a concern. District personnel were generally satisfied with a 30-year design life for the alternates; one interviewee mentioned that there are many unknowns when designing for the future in any case, so designs above 30 years may be problematic in that regard. The district is not planning to specify PFC on pavement alternates, either. However, the district plans to use conventional ACP specifications in the future since mixtures designed with those specifications have performed well and have not had the permeability issues that were observed with the Superpave mixtures on SH 114.

The district has not developed project selection criteria for pavement alternates. However, district personnel did recommend that effective drainage be considered when developing pavement designs; under-drains in particular need to be considered when developing drainage designs.

The district has not used A+B or A+B+C bidding on contracts. However, district personnel do think there is a benefit for using pavement alternates in terms of cost savings.

In terms of other construction related issues, when the contractor first started placing the Superpave base mixture on SH 114, temperature measurements behind the lay-down machine indicated that there was a thermal segregation issue. However, the contractor used a material transfer vehicle (MTV) afterward, and the resulting temperatures were more uniform. There were also issues with the Superpave mixture when placing in cool weather; one interviewee indicated that the mat tended to lose heat quickly, which made compaction problematic in some areas.

District personnel have not heard any position one-way or another concerning the use of pavement alternates from contractors. Both the CRCP and full depth ACP sections on SH 114 are performing well as of March 2008.

In retrospect, district personnel would have changed the design for the westbound lanes where the CRCP would be thinner (10 inches instead of 12) since the trucks traveling in that direction generally weigh less (SH 114 is a major route for aggregate haul trucks from pits in Wise County). There may have been a possibility that the concrete option would have been chosen if the CRCP were thinner.

As for future research, district personnel indicated that predicting future maintenance and using that in calculating projected maintenance costs is needed. In addition, research on the performance impacts of new pavement technologies is needed.

The district does not have any current plans for developing PS&E using pavement alternates, but there have been some discussions about it among district staff and area office personnel.

SAN ANTONIO DISTRICT

The San Antonio District let two projects using pavement alternates: IH 10 at Camp Bullis (a controlled access facility) and Spur 421 (a non-controlled access curb and gutter facility), both in San Antonio. The San Antonio District developed a district pavement design guide, but they normally follow the guidelines in the TxDOT Pavement Design Guide (*29*) to generate pavement designs with FPS-19W and the AASHTO rigid pavement design procedure. The district did not use A+B bidding on those projects (they have used such bidding on other projects, however).

The district's flexible pavement designs normally use a minimum time to first overlay of eight years. District personnel indicated that usually their ACP surfaces last for at least eight years in the southern part of the district and 10 years in the northern part before surface oxidation becomes a significant problem. The district then usually places seal coats on those oxidized surfaces. One interviewee mentioned that it appears that asphalt pavement surfaces provide better ride quality than concrete surfaces. Another interviewee indicated that, generally, the flexible pavement sections tend to be significantly thicker than rigid pavement sections, especially when high truck traffic is projected.

The respective contractors selected the rigid pavement alternate on IH 10 and the flexible pavement alternate on Spur 421. According to the district personnel interviewed for this research, the Spur 421 contractor chose the flexible pavement option because of the high number of driveways in the project area, and the contractor concluded that constructing rigid pavement in that situation would be difficult. District personnel decided to utilize alternates late in the design process for those projects; however, in the future, they plan to make the decision at the beginning of project design (the scoping phase), or at least by the time for the 30 percent plan review. In fact, district personnel discuss if a project is a candidate for pavement alternates during the project's design concept conference. So far, the district has not had any unexpected construction related issues with these two projects.

District personnel indicated that, in general, they did not consider it practical to place concrete pavement on rural farm to market roads and areas where only short pavement sections would be constructed (i.e., 100 feet or less). In addition, they would not consider placing concrete where additional lanes or shoulders are to be added to an existing flexible pavement facility. In considering whether to use alternates, district personnel would consider traffic control issues, project length, project width (which is a factor in determining effective traffic detours during construction), project size, and what type of work would be conducted (i.e., reconstruction versus adding lanes). One interviewee indicated that pavement alternates should not be considered on projects where significant utility relocation issues or access management issues are present. Another interviewee indicated that only rigid pavements should be placed where significant vehicle braking actions occur, such as at intersections and ramps. The district has used rigid pavement for several intersection projects.

The San Antonio District does have areas where expansive soils exist and the interviewees indicated that they would not consider placing concrete where such soils are moving due to active water sources. However, they noted that such movement did decrease when the roadway medians were paved, since that reduced the infiltration and evaporation of moisture from those soils.

District personnel also had some experience with the use of life-cycle cost estimates when determining what pavement type to use on an IH 10 construction project. On that project, the district decided to use rigid pavement, but it was based more on constructability issues than the life-cycle cost. One interviewee indicated that he is in favor of the life-cycle cost concept but has not seen it work properly in practice; it appears to him that the user costs are usually the major factor when generating life-cycle costs.

District personnel indicated that they would consider pavement alternates if the proposed project has a projected cumulative 18-kip equivalent single axle load value of at least two million.

The district may consider requiring PFC as the surface for both rigid and flexible alternate designs in the future. However, for flexible pavement designs, the district plans to stay with traditional dense-graded mixes (ACP Type B and C); they indicated that their experience with such mixes has been positive and they did not think they needed to change to Superpave or other designs. The district also believes that asphalt modifiers (such as polymers) have provided benefits in terms of asphalt pavement performance.

District personnel do believe that the use of pavement alternates results in cost savings. The district has used alternates for asphalt surfaces (i.e., PFC, SMA) and subgrade stabilization (i.e., lime versus cement) as well. District personnel believe that using such alternates results in increased competition and lower costs.

The interviewees did indicate that developing plans, specifications, and estimates is a challenge when pavement alternates are involved. For example, since one alternate may have a lesser total pavement depth than another on a particular project, the designer needs to take into account differences between excavations and fill quantities between the alternates. Other bid items, including those involving traffic control, would obviously be affected as well. One interviewee estimated that it takes about 10 to 30 percent more time for designers to develop PS&E for pavement alternate projects. District personnel also indicated difficulties when preparing estimates for alternates in the Design and Construction Information System, especially since the estimates for the alternates are required to be equal in terms of cost. One interviewee indicated it was “cumbersome” to develop such estimates in DCIS. In addition, on the IH 10 project when the contractor selected the rigid pavement option on the mainlanes, a change order had to be issued to include missing bid items. In addition, certain design details change depending on the pavement type. For example, traffic rail requires foundations if flexible pavements are used; however such foundations are not needed if rigid pavements are used.

In terms of utilities, the district uses the deepest section to determine utility placement when developing the plans; a cost savings could be realized in this area if the thinnest section is selected, but in any case the utility placement is not adjusted if the thinner section is used.

District personnel have received positive comments from contractors concerning the use of pavement alternates. One interviewee indicated that suppliers are more likely affected; the contractor's profit may not be affected by the use of alternates, but the supplier's profit may be affected. The interviewee also indicated that the contractors may see more projects advertised for letting, since the cost savings from projects using alternates can be used for funding other projects. In addition, district personnel indicated that contractors are available in their area to construct either flexible or rigid pavements. Also, the district does penalize contractors if lanes are closed longer than what is allowed in the plans.

District personnel indicated that research was needed to develop procedures to ensure that pavement alternate designs perform comparably over their respective design life-cycles; and to find out the differences in long-term maintenance costs between rigid and flexible pavements. The interviewees also wondered if rigid pavement designs actually performed with minimal maintenance over 30 years, which is currently the assumption for rigid pavement design. One person indicated that the year to first overlay is a significant issue when developing alternates. In addition, some urban projects that have bridge vertical clearance issues could not handle significantly thick future overlays since it would involve raising those bridges; therefore, flexible pavement designs for those projects would have to restrict the total thickness of such overlays. As one interviewee stated, "We are designing them based on our best guesses and our general conservative natures."

CONSTRUCTION DIVISION

TxDOT's Construction Division has developed the following guidelines concerning the design of pavement alternates for new construction and reconstruction projects:

- Use 30 years as the design life.
- Use 4.5 and 2.5 for the initial and terminal serviceability values, respectively.
- Use 95 percent reliability.
- Use a time to first overlay of 15 years for the flexible pavement design.
- Design the overall subgrade and pavement structure to have a Potential Vertical Rise (PVR) no greater than 1.0 inch as calculated by Tex-124-E from soil tests in a soil column 15 feet deep as measured from the proposed finished pavement grade. Alternatively, provide material with an Effective Plasticity Index of less than 25, to a depth of 8 feet from finished pavement surface.

In addition, division personnel had the following comments:

- About double the effort is need[redacted]velop a set of plans that include alternates.

- Some sort of life-cycle cost ana[redacted]ls to be used when developing alternates, especially during th[redacted]stage. At the moment, user costs are not adequately addressed. There does not appear to be a palatable user cost methodology where the user costs do not significantly outweigh the material costs. There needs to be a reasonable way to evaluate user costs; user delay costs need to be considered for the pavement's life-cycle (not just during initial construction), such as delays due to maintenance and rehabilitation activities. The LCCA system will have to be flexible enough so that the designer can conduct a bonafide side-by-side comparison. Realistic salvage values need to be developed (at this time, the Construction Division has not recently generated salvage value recommendations; however, there are recommended values in the FPS-19W flexible pavement design computer program). There are some factors that cannot be obtained accurately for use in a LCCA, such as future truck traffic generators; in those cases, engineering judgment would have to be used (the cumulative number of 18-kip equivalent single axle loads projected by TxDOT has generally been less than what was actually applied on those projects).

- One possible approach to using LCCA is to develop different levels of analysis depending on the project; for example, level one considers TxDOT expenses only, level two considers TxDOT expenses and user costs, and level three is TxDOT expenses, user costs, and salvage values.
- Higher modulus values (other than 500 ksi) for certain asphalt pavement layers such as SMAs and thick hot mix layers (minimum of 6 to 8 inches) should be used in design. Recommendations for such values are in the TxDOT Pavement Design Guide (*29*). Use PG 76 binders for the upper 4 to 6 inches of high truck traffic full-depth HMA structures to improve shear strength.
- PFC should not be given structural credit in design, but if comparing rigid and flexible systems, use PFC on both or not at all. You can use 300 ksi as a structural value but generally it is not treated as a structural layer as stated in the TxDOT Pavement Design Guide (*29*).
- There have been constructability issues with multilayer HMA structures, including harsh mix designs generated for lower layers. One recommendation to address this issue is to use conventional dense-graded mixtures for the bottom layers and the specialty mixes such as SMA on the upper layers. Longitudinal joint density issues have been a problem as well. There have been permeability issues for perpetual pavements, and a longitudinal cracking problem occurred recently on a perpetual pavement project. Also, there was a problem with an SMA on one project where the asphalt content was 5.5 percent (instead of a minimum of 6 percent, which TxDOT currently recommends).
- A minimum number of lane miles could be a requirement for considering pavement alternates (such as a minimum of 2 to 4 lane miles), but a certain dollar threshold or cumulative 18KESAL threshold (such as a minimum of 15 million 18KESALs forecast over 20 years that usually results in a 10 inch thick concrete slab thickness) could be a possibility as well.
- If the project scope is large enough, large contractors would want to bid on such projects, so local availability of contractors may not be a factor.
- Subgrade conditions should be a factor and addressed ahead of time (in the design process). Rigid pavements should not be used if there are subgrade issues that cannot be effectively addressed during initial construction.

- Alternates should not be considered where the proposed pavement structure would match an adjoining section, if the existing pavement structure is to be widened, or if there are utility concerns where it would not be desirable to use rigid pavement.
- For flexible pavement design, the districts should be allowed to vary the minimum time to first overlay depending on their experience and conditions.
- Using bid items that base payment by the ton rather than by the square yard may be desirable when developing alternates. If square yard measurements are used, then the pavement thicknesses need to be checked, which could be problematic.
- Adjustment factors for maintenance and rehabilitation should not be used until more data are obtained from existing pavements.
- Consider developing pavement design alternate catalogs for different regions of the state.
- Using design periods above 30 years may be problematic. It would be more difficult, for example, to determine facility needs (such as capacity and alignment needs) 50 years from now than 30 years from now.
- For projects where the spacing between bridges is around a half mile, it may not be practical to use flexible pavements.
- For full depth asphalt concrete pavement projects that use large stone bases, designers may want to consider specifying edge drains, since such bases tend to be permeable.
- In areas where truck traffic is stopped for a long period of time or where fuel spills are a concern, rigid pavement may be the preferred option.
- For construction projects that last for two years or more, uncertainty in material costs becomes a big factor, so the contractor will most likely consider this issue if the plans contain alternates.
- Research is needed to determine actual pavement lives (including if rigid pavements actually need little to no maintenance over their design lives). Rational mechanistic-empirical design methods are needed as well.

DESIGN DIVISION

The Design Division personnel also expressed the same comments as stated earlier in this chapter. The following is a summary of their comments:

LCCA analyses need to be conducted for projects using pavement alternates. Differences in bid prices among districts need to be factored into LCCA procedures.

Division personnel indicated that A+B bidding has not been used recently, possibly because of the difficulty in calculating road-user costs. A+B+C bidding (where C is the adjustment factor between the alternates based on anticipated maintenance and rehabilitation activities) would be the preferred way of bidding alternates in the future.

Traffic control differences between the alternates could be the deciding factor in terms of which one the contractor selects. Some thicker flexible pavement designs require multiple lifts that could result in more complicated traffic control plans than with rigid pavements.

Hydraulic issues may be a concern on some projects if the thickness difference between the alternates is significant.

In conclusion, one of the interviewees stated, “if you are going to put alternates in the contract make sure your pavement designs are such that you will be equally happy with either one.”

CHAPTER 4:
SIDE-BY-SIDE COMPARISON OF PAVEMENT DESIGNS USING CURRENT TXDOT METHODS

A side-by-side comparison of current TxDOT pavement design methods, Flexible Pavement System (FPS-19W), and the 1993 AASHTO Guide (*31*), was conducted to get additional insights about pavement design methods. The focus was to study what adjustment factor(s), if any, should be considered for equivalent pavement alternate designs.

Factors involved in the comparison of pavement designs and pavement type selection were identified in previous chapters. General guidelines currently used by TxDOT concerning the design of pavement alternates for new construction and reconstruction projects are to:

- Use 30 years as the design life.
- Use 4.5 and 2.5 for the initial and terminal serviceability values, respectively.
- Use 95 percent reliability.
- Use a time to first overlay of 15 years for the flexible pavement design.
- Design the overall subgrade and pavement structure to have a Potential Vertical Rise no greater than 1.0 inch as calculated by Tex-124-E from soil tests in a soil column 15 feet deep as measured from the proposed finished pavement grade. Alternatively, provide material with an Effective Plasticity Index of less than 25, to a depth of 8 feet from finished pavement surface.

CONSIDERATIONS FOR EQUIVALENT PAVEMENT DESIGNS

In order to develop equivalent designs, the data inputs for both rigid and flexible pavement designs must first be standardized. The following design parameters require standardization:

a. Present Serviceability Index: Both of the accepted TxDOT pavement design procedures use the Present Serviceability Index concept for quantifying pavement performance. The TxDOT pavement design guide (*29*) recommends that an initial PSI of 4.5 and a terminal PSI of 2.5 be used for all rigid pavement designs, and for flexible pavement designs the initial PSI is usually recommended to be 4.2, with 3.8 for surface treated flexible pavements, and 4.5 for thicker hot mix asphalt pavements. Also, the terminal PSI is recommended to be 3.0 for all major routes and highways of national significance, 2.5 for other routes (such as US, State Highway, and Farm to Market [FM] roads), and 2.0 for low volume FM routes (those with an ADT less than 1,000 vehicles per day). The serviceability levels used for the comparison were first an initial PSI of 4.5 and a terminal PSI of 2.5; and later an initial PSI of 4.0 and a terminal PSI of 2.0 for both rigid and flexible designs. Also, a PSI of 4.2 after an overlay is used for the flexible pavement designs.

b. Reliability: The procedures use different approaches for incorporating reliability in pavement design. The TxDOT pavement design guide currently recommends using 95 percent reliability for most rigid pavement projects and an overall standard deviation value of 0.39 (as stated in the October 2006, TxDOT pavement design manual). The AASHTO Guide recommends values in the range of 0.30 to 0.40, with 0.35 being the overall standard deviation from the AASHO Road Test. For the side-by-side comparison, the overall standard deviation used for rigid pavement design was 0.39. Two reliabilities were used for rigid pavement design, 95 percent and 99 percent.

c. Standard Deviation: There is no overall standard deviation input for the FPS-19W procedure; reliability is specified using a design confidence level. For most projects, TxDOT recommends confidence level C, which relates to a 95 percent reliability level as indicated in the TxDOT pavement design guide (*29*). This is the confidence level used for the flexible pavement design.

d. Environmental Effects: The procedures take into account environmental effects differently. For rigid pavement design, TxDOT considers the effects of rainfall in the drainage coefficient, which is selected based on the projected average annual rainfall in the project area. The drainage coefficient used at the El Paso District is 1.16, since the rainfall is 8 inches per year; in Dallas, the drainage coefficient of 1.01 was used, since the rainfall is 38 inches per year; and in San Antonio a drainage coefficient of 1.05 was used, for 30 inches per year of rainfall. For flexible pavement designs using FPS-19W, a district temperature constant is used to characterize the affect of temperature on flexible pavement performance; each district has an assigned temperature constant. El Paso has a temperature constant of 24, Dallas 26, and San Antonio 31.

e. Traffic Projection: The procedures differ in terms of how the traffic projection data are used (the data are provided by TxDOT's Transportation Planning and Programming Division, or TPP). The TxDOT pavement design manual requires a 30-year truck traffic projection (cumulative 18-kip equivalent single axle loads, or 18 KESALs) for rigid pavement designs; however, for flexible designs, a 20-year projection is used in FPS-19W, and most TxDOT- developed flexible pavement designs use a 20-year analysis period. However, FPS-19W can extrapolate the 20-year traffic projection to 30 years or more if the designer specifies a longer analysis period. In order to compare equivalent designs, a 30-year analysis period was used.

f. Maintenance and Rehabilitation: TxDOT rigid pavement design procedure implies that no major maintenance or rehabilitation will be required on rigid pavements for 30 years. However, TxDOT's flexible pavement design procedure recommends that the initial pavement structure performs for at least eight years before an overlay is needed. This indicates that for flexible pavements substantial rehabilitation costs will need to be incurred to achieve the same design life. These factors must be accounted for in the total cost calculation. It will also be critical to assume realistic salvage values at the end of the design life. If the concrete pavement needs to be reconstructed at the end of the design life then a small or negative salvage value needs to be considered.

FACTORIAL PAVEMENT DESIGNS

A factorial of equivalent designs was generated to compare pavement designs. Pavement designs were developed for the same serviceability range, traffic levels, environmental conditions, and subgrade conditions. The dimensions of this factorial are summarized as follows:

- Four traffic levels: Very Low (1 million 20 year 18 KESALs), Low (5 million), intermediate (15 million), and high (30 million).

- Three environmental conditions. The team nominated three districts representative of the environmental conditions found around the state, which were El Paso, Dallas, and San Antonio Districts. The temperature constant for the selected districts were 24, 26, and 31, respectively.
- Two subgrade support conditions (poor, 8 ksi; and good, 15 ksi).

For each of the 24 combinations, flexible and rigid pavement designs were generated. Table 9 shows the factorial with data inputs used for flexible pavement designs for this purpose. Table 10 shows the factorial with data inputs used for rigid pavement designs.

Table 9. Factorial Used for Flexible Pavement Designs.

Traffic Level	**Very Low (1 million 20-year ESALs)**	**Low (5 million 20-year ESALs)**	**Intermediate (15 million 20-year ESALs)**	**High (30 million 20-year ESALs)**
Environmental Condition – District	El Paso / Dallas / San Antonio			
Subgrade Support Conditions (ksi)	8 ksi / 15 ksi			

Table 10. Factorial Used for Rigid Pavement Designs.

Traffic Level	**Very Low (1 million 18-year ESALs)**	**Low (5 million 18-year ESALs)**	**Intermediate (15 million 18-year ESALs)**	**High (30 million 18-year ESALs)**
Environmental Conditions – Districts	El Paso / Dallas / San Antonio			
Rain (in/year)	El Paso: 8 / Dallas: 38 / San Antonio: 30			
Drainage Coefficient	El Paso: 1.16 / Dallas: 1.01 / San Antonio: 1.05			

SIDE-BY-SIDE COMPARISON

Based on the factorial pavement designs, seven cases for flexible pavements and three cases for rigid pavements were considered for the side-by-side comparison.

Flexible Pavement Designs

Seven cases, "A" through "G," were analyzed for flexible pavement designs. For the purpose of analysis, the minimum time to first overlay was constrained, first to 8 years, then to 15, and finally to 30 years. The modulus of the ACP layer and the ACP base was also varied from 500 ksi to 650 ksi for each case. The modulus of the flexible base was set to 24 ksi for the poor subgrade condition (8 ksi) and 45 for the good subgrade condition (15 ksi). The modulus of the lime treated subgrade was fixed at 35 for all cases. Flexible pavement designs were obtained for four traffic levels and two serviceability index ranges (4.0 to 2.0, and 4.5 to 2.5).

Case A

The pavement layer structure shown in Table 11 was used to run this case. The ACP layer was fixed at 2 inches to see the variation on the asphalt stabilized base and the flexible base. These runs were first completed with an initial PSI of 4.5 and a terminal PSI of 2.5. They were later done with an initial PSI of 4.0 and a terminal PSI of 2.0. Two different "minimum times to first overlay" were used for these cases: 15 years and 30 years.

Table 11. Pavement Layer Structure for Case A.

Material	**Moduli (ksi)**		**Minimum Thickness (in)**	**Maximum Thickness (in)**
ACP	500	650	2	2
Asphalt Stabilized Base	500	650	4	20
Flexible Base	24	45	6	12
Subgrade	8	15	240	240

Appendix A shows results for pavement designs. The following observations can be made about these designs:

- For the lower PSI range (4.0 to 2.0), the asphalt stabilized base was about 0.5 inch (low traffic levels) to 1 inch thicker (high traffic level) than for the higher PSI range (4.5 to 2.5).
- For the high traffic levels (30 million ESALs) with an ACP and Asphalt Stabilized Base (ASB) modulus of 500 ksi, no feasible design was obtained when the time to first overlay was set to 30 years. However, when the time to first overlay was set to 15 and 8 years, feasible designs with thick asphalt stabilized bases were obtained (11 to 20 inches).
- The flexible base was 6 to 8 inches in most of the cases, except for some of the higher traffic levels (15 to 30 million 20-year ESALs), where it went up to 11 to 12 inches.
- For the lower modulus of the ACP layer (500 ksi), the asphalt stabilized base was about 1½ inch (low traffic levels) to 3 inches thicker (high traffic level) than for the higher modulus (650 ksi).

Case B

The pavement layer structure shown in Table 12 was used to run this case. The ACP layer was fixed at 2 inches to see the variation on the thickness of the asphalt stabilized and flexible bases. These runs were first completed with an initial PSI of 4.5 and a terminal PSI of 2.5. They were later done with an initial PSI of 4.0 and a terminal PSI of 2.0. Two different “minimum times to first overlay” were used for these cases: 15 years and 30 years.

Table 12. Pavement Layer Structure for Case B.

Material	Moduli (ksi)		Minimum Thickness (in)	Maximum Thickness (in)
ACP	500	650	2	2
Asphalt Stabilized Base	500	650	6	16
Flexible Base	24	45	6	20
Subgrade	8	15	240	240

Results for pavement designs are shown in Appendix A. The following observations can be made about these runs:

- For the lower PSI range (4.0 to 2.0), the asphalt stabilized base was about ½ inch (low traffic levels) to 1 inch thicker (high traffic level) than for the higher PSI range (4.5 to 2.5).
- For high traffic levels (30 million ESALs) no feasible design was obtained when the time to first overlay was set to 30 years. However, when the time to first overlay was set to 15 years, thick AS bases were obtained (15 to 16 inches).
- The flexible base was 6 to 8 inches in most of the cases, except for some of the higher traffic levels (15 to 30 million 20-year ESALs).
- When the 'time to first overlay' was fixed at 30 years, the ASB layer was thicker than when the time to first overlay was fixed at 15 years. This ranged from 3 to 5 inches, depending on the traffic level.
- When the ACP and ASB moduli were fixed at 500 ksi, the thickness of the ASB layer was 1.5 inches to 3 inches thicker than when the moduli of both layers was fixed at 650 ksi, depending on the traffic level.

Case C

The pavement layer structure shown in Table 13 was used to run this case. In this case, the ACP layer was allowed to vary in the range of 2 to 20 inches, but both the flexible base and the lime treated subgrade were fixed at 6 and 8 inches, respectively. Again, these runs were first completed with an initial PSI of 4.5 and a terminal PSI of 2.5. They were later done with an initial PSI of 4.0 and a terminal PSI of 2.0. Three different "minimum times to first overlay" were used for these cases: 8 years, 15 years, and 30 years.

Table 13. Pavement Layer Structure for Case C.

Material	Moduli (ksi)		Minimum Thickness (in)	Maximum Thickness (in)
ACP	500	650	2	20
Flexible Base	50		6	6
Lime Treated Subgrade	35		8	8
Subgrade	8	15	240	240

Results for pavement designs are shown in Appendix A. The following observations can be made about these runs:

- For the lower PSI range (4.0 to 2.0), the ACP layer was about ½ (low traffic levels) to 1 inch thicker (high traffic level) than for the higher PSI range (4.5 to 2.5).
- For lower modulus, 500 ksi, the ACP layer was about ½ (low traffic levels) to 1 inch thicker (high traffic level) than for higher modulus, 650 ksi.
- As the "years to first overlay" increase, so does the thickness of the ACP layer.
- No feasible design was found for high traffic levels (30 million ESALs) and 30 years to first overlay.

Case D

The pavement layer structure shown in Table 14 was used for this case. In this case, the ACP layer was allowed to vary in the range of 2 to 20 inches, but both the flexible base and the lime treated subgrade were fixed at 6 and 18 inches, respectively. Again, these runs were first completed with an initial PSI of 4.5 and a terminal PSI of 2.5. They were later done with an initial PSI of 4.0 and a terminal PSI of 2.0. Three different "minimum times to first overlay" were used for these cases: 8 years, 15 years, and 30 years.

Table 14. Pavement Layer Structure for Case D.

Material	Moduli (ksi)		Minimum Thickness (in)	Maximum Thickness (in)
ACP	500	650	2	20
Flexible Base	50		6	6
Lime Treated Subgrade	35		18	18
Subgrade	8	15	240	240

Results for pavement designs are shown in Appendix A. The following observations can be made about these runs:

- For the lower PSI range (4.0 to 2.0), the ACP layer was about ½ (low traffic levels) to 1 inch thicker (high traffic level) than for the higher PSI range (4.5 to 2.5). Although for the Very Low and Low traffic levels with 8 years to first overlay, the thicknesses were about the same.
- For lower modulus, 500 ksi, the ACP layer was about ½ (low traffic levels) to 2.5 inches thicker (high traffic level) than for higher modulus, 650 ksi.
- As the "years to first overlay" increase, so does the thickness of the ACP layer.
- A feasible design was found for almost all the cases, except for the high traffic levels (30 million ESALs) with low ACP modulus (500 ksi) and 30 years to first overlay.

Case E

The pavement layer structure shown in Table 15 was used for this case. In this case, the ACP layer was allowed to vary in the range of 2 to 20 inches, the flexible base was allowed to vary between 4 and 16 inches, and the lime treated subgrade was fixed at 8 inches. Again, these runs were first completed with an initial PSI of 4.5 and a terminal PSI of 2.5. They were later done with an initial PSI of 4.0 and a terminal PSI of 2.0. Three different "minimum times to first overlay" were used for these cases: 8 years, 15 years, and 30 years.

Table 15. Pavement Layer Structure for Case E.

Material	Moduli (ksi)		Minimum Thickness (in)	Maximum Thickness (in)
ACP	500	650	2	20
Flexible Base	50		4	16
Lime Treated Subgrade	35		8	8
Subgrade	8	15	240	240

Results for pavement designs are shown in Appendix A. The following observations can be made about these runs:

- The flexible base was fixed at 4 to 6 inches in most of the cases and above 10 inches in some of them.
- In the cases where the flexible base was 4 to 6 inches, the ACP layer ranged from 2 inches (for lower traffic levels) to 20 inches (for higher traffic levels).
- No feasible design was found for high traffic levels (30 million ESALs) with a minimum of 30 years to first overlay, when the modulus of the ACP layer was 500 ksi. This is true for both SI ranges.

Case F

The pavement layer structure shown in Table 16 was used for this case. In this case, the ACP layer was allowed to vary in the range of 2 to 10 inches, the flexible base was allowed to vary in the range of 6 and 18 inches, and the lime treated subgrade was fixed at 18 inches. Again, these runs were first completed with an initial PSI of 4.5 and a terminal PSI of 2.5. They were later done with an initial PSI of 4.0 and a terminal PSI of 2.0. This case was the only case done for Very Low Traffic (1 Million 20-years ESALs). Three different “minimum times to first overlay” were used for these cases: 8 years, 15 years, and 30 years.

Table 16. Pavement Layer Structure for Case F.

Material	Moduli (ksi)		Minimum Thickness (in)	Maximum Thickness (in)
ACP	500	650	2	10
Flexible Base	24	45	6	18
Lime Treated Subgrade	35		18	18
Subgrade	8	15	240	240

Results for pavement designs are shown in Appendix A. The following observations can be made about these runs:

- In most of the cases, the flexible base was 6 to 8 inches thick. In some of the San Antonio or Dallas District projects, this layer jumped to 18 inches thick.
- The ACP layer was in the range of 2 to 6 inches. As the “minimum years to first overlay” increase, so does the thickness of the ACP layer.
- The thickness of the ACP layer decreases when the district temperature constant increases, but the flexible base thickness increases (for a minimum of 15 and 30 years to overlay). For minimum of 8 years to first overlay it was fixed at 6 inches (for PSI 4.0 to 2.0). When the initial PSI was 4.5 and the terminal PSI was 2.5, the flexible base was 6 inches for 15 years to first overlay as well.

Case G

The pavement layer structure shown in Table 17 was used for this case. In this case, the ACP layer was allowed to vary in the range of 2 to 10 inches, and the flexible base was allowed to vary in the range of 6 to 18 inches. The lime treated base was eliminated in this case, and the flexible base was set directly on top of the subgrade. These runs were first completed with an initial PSI of 4.5 and a terminal PSI of 2.5. They were later done with an initial PSI of 4.0 and a terminal PSI of 2.0. Two different “minimum times to first overlay” were used for the 500 ksi cases: 8 years and 15 years. When the ACP modulus was set to 650 ksi, the “minimum time to first overlay” was set to 30 years.

Table 17. Pavement Layer Structure for Case G.

Material	Moduli (ksi)		Minimum Thickness (in)	Maximum Thickness (in)
ACP	500	650	2	10
Flexible Base	24	45	6	18
Subgrade	8	15	240	240

Results for pavement designs are shown in Appendix A. The following observations can be made about these runs:

- The ACP modulus is not a large influence factor when very low traffic (1 million ESALs) is considered. For a higher modulus (650 ksi) a thinner ACP layer results in a range of about ½ to 1 inch.

The FPS-19W program calculates the initial construction cost, overlay construction cost, user cost, routine maintenance cost, salvage cost, and the total cost of the pavement for the different designs in dollars per cubic yard. Based on the lowest cost given for each design, the following comments are made:

- When selecting the minimum time to first overlay to 30 years, the designs return very thick pavements. These pavement structures cost a lot more than when the minimum time to first overlay is set to either 15 or 8 years. This trend was observed in all the cases.
- It seems to be cheaper to build a pavement and place an overlay after 8 years, than to build a pavement to last 15 or 30 years without any major work done to it.
- When the time to first overlay was set to 30 years, the user costs given by the FPS-19W were zero.

Rigid Pavement Designs

Rigid pavement designs were obtained using the AASHTO 1993 Design Guide procedure (*31*). A typical rigid pavement structure used by TxDOT in general construction practices was selected; that is, to place the concrete slab on top of one of the following layers:

a. 4 inches of asphalt concrete pavement on top of 8 inches of lime treated subgrade,

b. 1 inch of asphalt concrete pavement on top of 6 inches of cement stabilized base, on top of 8 inches of lime treated subgrade, and

c. 4 inches of asphalt concrete pavement on top of 18 inches of lime treated subgrade.

Different constraints were considered in the designs. The 28-day concrete modulus of rupture was 620 psi for all cases. The 28-day concrete elastic modulus was 5 million psi for all cases, the effective modulus of the subgrade reaction, k-value, was 10, 300, and 1000 pci for each case. Rigid design was obtained for each of these cases, for the given traffic levels and the two serviceability index ranges (4.0 to 2.0, and 4.5 to 2.5). These rigid pavement designs were also done with an increase in the number of ESALs, that is 1.58 million, 7.91 million, 15.81 million, and 47.43 million 18 KESALs. This was done based on the research supervisor's observations of TxDOT traffic analysis reports when he was Fort Worth District Pavement Engineer. The total number of rigid 18 KESAL's is generally higher than the flexible 18 KESAL's.

Results for rigid pavement designs are also shown in Appendix A. The following observations can be made for rigid pavement designs:

Case A

The pavement layer structure shown in Table 18 was used to run this case. The ACP layer was fixed at 4 inches, and the lime treated subgrade was fixed at 8 inches to see the variation on the concrete slab. These runs were first completed with an initial PSI of 4.5 and a terminal PSI of 2.5. They were later done with an initial PSI of 4.0 and a terminal PSI of 2.0.

Table 18. Pavement Layer Structure for Rigid Case A.

Material	28-day Modulus of Rupture (psi)	Thickness (in)
Concrete Slab	620	To calculate
ACP	-	4
Lime Treated Subgrade	-	8

Case B

The pavement layer structure shown in Table 19 was used to run this case. The ACP layer was fixed at 1 inch, a cement treated base of 6 inches, and the lime treated subgrade was fixed at 8 inches to see the variation on the concrete slab. These runs were first completed with an initial PSI of 4.5 and a terminal PSI of 2.5. They were later done with an initial PSI of 4.0 and a terminal PSI of 2.0.

Table 19. Pavement Layer Structure for Rigid Case B.

Material	28-day Modulus of Rupture (psi)	Thickness (in)
Concrete Slab	620	To calculate
ACP	-	1
Cement Treated Base	-	6
Lime Treated Subgrade	-	8

Case C

The pavement layer structure shown in Table 20 was used to run this case. The ACP layer was fixed at 4 inches, and the lime treated subgrade was fixed at 18 inches to see the variation on total cost. These runs were first completed with an initial PSI of 4.5 and a terminal PSI of 2.5. They were later done with an initial PSI of 4.0 and a terminal PSI of 2.0.

Table 20. Pavement Layer Structure for Rigid Case C.

Material	28- day Modulus of Rupture (psi)	Thickness (in)
Concrete Slab	620	To calculate
ACP	-	4
Lime Treated Subgrade	-	18

Results for rigid pavement designs are shown in Appendix A. The following observations can be made about these runs:

- The serviceability index does not make an observable difference for different PSI ranges. The slab thicknesses were about 0.1 inch thicker, on average, for the higher range (4.5 to 2.5).
- The thickness of the concrete slab is about 3 inches thicker for low k-values (10 pci) compared to higher k-values (1000 pci) for Very Low traffic. This number is about 2 inches thicker for the rest of the traffic levels.
- For higher design confidence levels (99 percent), the design gave thicker slabs (about 1 inch on average).
- When the traffic levels were increased by 58 percent (which is comparable to the increase from flexible ESALs to rigid ESALs calculated by TxDOT's Transportation Planning and Programming Division for traffic analysis reports), the slab thickness increased from ½ inch (lower traffic levels) to about 1 inch (higher traffic levels).
- The trend in costs shows that placing the concrete slab over 1 inch of ACP on top of 6 inches of CSB, on top of 8 inches of Lime Treated Sub grade (LTS) is the most cost effective.

LIFE-CYCLE COST ANALYSIS

Life-cycle cost analysis procedure is desired when developing alternates, especially during the preliminary design stage. Life-cycle cost analyses are used for the prediction of future costs of proposed pavements over a given period of time, using the best available information as to total costs and predicted performance. Pavement designs will consider similar traffic and comparable age for the alternatives (*7*).

The analysis takes into consideration: initial construction and routine maintenance costs, and also considers the salvage value of the pavement. First an analysis without including the user costs was done. However, these costs will be included later for selected pavement design configurations. A definition of the terms used in the analysis follows:

- Equivalent Single Axle Loads: This approach converts axle configurations and axle loads of various magnitudes and repetitions ('mixed traffic') to an equivalent number of 'standard' or 'equivalent' loads. The most commonly used equivalent load in the

U.S. is the 18,000 1b (80 kN) equivalent single axle load (normally designated ESAL) (*29*).

- Present Serviceability Index: Serviceability is a concept derived during the AASHO Road Test. This concept is related to the primary function of a pavement structure: to provide the traveling public with a smooth, comfortable, and safe ride. A scale ranging from 0 to 5 is used to evaluate a pavement's present serviceability index; pavement with a rating of zero is impassible, and a rating of 5.0 would be perfectly smooth *(29*).
- Minimum Time to First Overlay: An input in the FPS-19W software. It defines the length of time that the initial design must last before placing an overlay. This is a district option; however, the minimum recommended value is eight years (*30*).
- Initial construction costs: These include all costs incurred by agencies to procure the pavement construction.
- Routine Maintenance Costs: Pavement maintenance activities are typically grouped into two categories: (1) annual routine maintenance, which includes minor and spot work (e.g., pothole repair), and (2) preventive maintenance, which includes periodic pavement work (e.g., crack seal and seal coat activities) (*31*).
- Salvage Value: The salvage value of a pavement structure at the end of the analysis period is one of the most controversial issues in an LCCA. If a dollar value can be assigned to a given pavement structure at the end of the analysis period, then that value can be included in the LCCA as a salvage or residual value (*31*).
- User Costs: The literature shows two broad categories for pavement-related user costs:
    - Vehicle operating costs, where the function of a VOC is: (1) to simulate the effects of the physical characteristics and condition (roughness) of a road on the operating speeds of various types of vehicles and on their consumption of resources (fuel, lubricants, tires), and (2) to determine their total operating cost.
    - User costs associated with work zone activities: These costs primarily include user delay costs resulting from lower operating speeds, stops, stop-and-go travel, and speed-change cycling.

Some other user costs, such as travel time, denial-of-use cost, discomfort cost, and accident cost, are also mentioned, but there is little evidence that they are considered by agencies (*40*, *41*, *42*).

- Discount Rate: Cash flow streams are converted to Net Present Worth (NPW) by using discount rates so that the economic worth of different alternatives can be compared. The discount rate used in an agency's cash flow calculations is a policy decision that may vary with the purpose of the analysis, the type of agency, and with the degree of risk and uncertainty.
- Analysis Period: The analysis period is the time period used in comparing relative economic worth of pavement alternates (*39*).
- Net Present Worth Method: The NPW method involves conversion of all present and future costs to the present using an appropriate discount rate. All costs are predicted and are reduced to an ***e***quivalent single cost. Present-worth costs of the strategies provide a fair comparison basis, all other things being equal (*31*).

Three flexible pavement and one rigid pavement structure were selected for further life-cycle cost analysis. The selection was based on typical pavement structures used in previous TxDOT designs. Since there were 8 to 12 sub-cases within each of the cases, the best choice, cost-wise was selected. Table 21 shows the unit material costs used in the life-cycle cost analyses.

Table 21. Material Costs Used for Flexible and Rigid Pavement Designs (*).

Material	**Cost**
ACP	185 – 200 $/cy
Asphalt Stabilized Base	180 $/cy
Cement Stabilized Base	48 $/cy
Flexible Base	40 $/cy
Lime Treated Sub grade	20 $/cy
Concrete	45 $/sy **
	55 $/sy ***

* based on data from http://www.dot.state.tx.us/business/avgd.htm
** for slabs 8 to 13 inches thick
*** for slabs 14 to 15 inches thick

Flexible Pavement Designs

Case B

The flexible pavement design is shown in Table 22.

Table 22. Pavement Structure Used in Flexible Case B.

Material	Thickness (in)
ACP	2
Asphalt Stabilized Base	11
Flexible Base	6

Note: 2.5 inch overlay is scheduled for this case on year 16.

The pavement design parameters in this case were:

- 15 years to first overlay,
- ACP Base Modulus of 500 ksi for layer < 8 inches,
- ACP Base Modulus of 650 ksi for layer ≥ 8 inches, and
- Serviceability Range: 4.5 – 2.5.

Case C

The flexible pavement design is shown in Table 23.

Table 23. Pavement Structure Used in Flexible Case C.

Material	Thickness (in)
ACP	9.5
Flexible Base	6
Lime Treated Subgrade	8

Note: 2.5 inch overlay is scheduled for this case on year 9 and then on year 20.

The pavement design parameters in this case were:

- Eight years to first overlay,
- ACP Modulus of 500 ksi for ACP layer < 8 inches,

- ACP Modulus of 650 ksi for ACP layer ≥ 8 inches, and
- Serviceability Range: 4.5 – 2.5.

Case E

The flexible pavement design is shown in Table 24.

Table 24. Pavement Structure Used in Flexible Case E.

Material	Thickness (in)
ACP	9.5
Flexible Base	4
Lime treated Subgrade	8

Note: 2.5 inch overlay is scheduled for this case on year 9 and then on year 19.

The pavement design parameters in this case were:

- Eight years to first overlay,
- ACP Modulus of 500 ksi for ACP layer < 8 inches,
- ACP Modulus of 650 ksi for ACP layer ≥ 8 inches, and
- Serviceability Range: 4.5 – 2.5.

Rigid Pavement Design

Case C

The rigid pavement design is shown in Table 25.

Table 25. Pavement Structure Used in Rigid Case C.

Material	Thickness (in)
Concrete Slab	12
ACP	1
Cement Treated Base	6
Lime Treated Subgrade	8

The pavement design parameters in this case were:

- Serviceability Range: 4.5 – 2.5 and
- Design Confidence Level: 95 percent.

Life-Cycle Cost Analysis Excluding User Costs

RealCost, a software developed by the FHWA, was used to calculate LCCA excluding user costs (*43*). Discount rates of 4 and 7 percent were used. These were the lowest cost alternatives from the feasible designs obtained from the side-by-side comparison. The high traffic level (30 million ESALs) and good subgrade conditions (15 ksi for flexible and 300 pci for rigid) were used for life-cycle cost analysis.

Table 26 shows the present value of all the alternatives in dollars per lane mile ($/lane mile) when user costs were not included.

Table 26. Results of RealCost without User Costs.

Present Value Cost ($/lane mile)				
Case	**Flexible**	**Flexible**	**Rigid Design C**	
Discount Rate (%)	7	4	7	4
B	523,750	527,550	466,640	468,620
C	449,310	460,490	466,640	468,620
E	463,970	476,120	466,640	468,620

It is observed that when comparing the pavement layer structure shown in Table 22 (Case B) with the rigid pavement alternate shown in Table 25, the second one is a better choice, cost-wise. However, when comparing the rigid design with the pavement layer structure shown in Table 21 (Case E), the discount rate plays an important role. With a discount rate of 7 percent flexible pavement design is a better choice; with a discount rate of 4 percent, the rigid pavement design is a better choice. The pavement structure shown in Table 23 (Case C) gives the best overall cost.

It is very important to mention the significance of the scheduled overlays in these layer structures. The ACP thickness for Cases C and E are identical, but the flexible base is 2 inches thicker for Case C. These 2 inches give the pavement a whole year of life until the next overlay, therefore reducing the Net Present Cost of that pavement by about 15,000 $/per lane mile. Figure 10 and Figure 11 show a summary of the costs in dollars per lane mile with a 4 percent discount rate and a 7-percent discount rate, respectively.

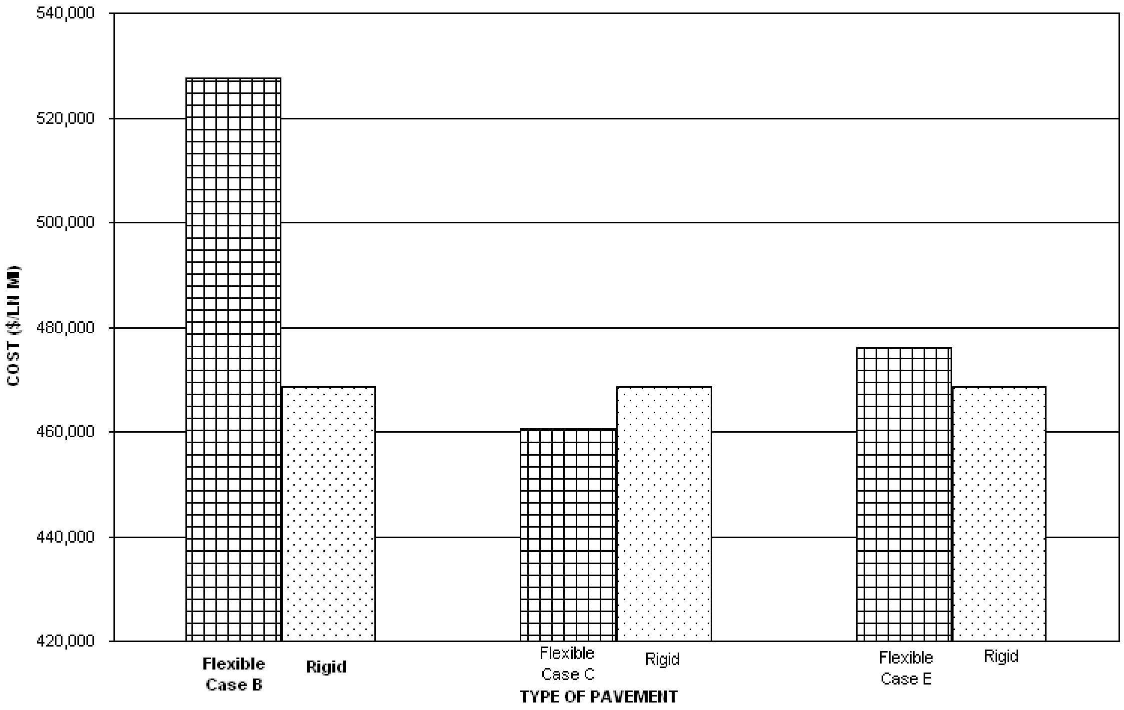


Figure 10. Cost Comparison Flexible vs. Rigid Cases with a 4 Percent Discount Rate.

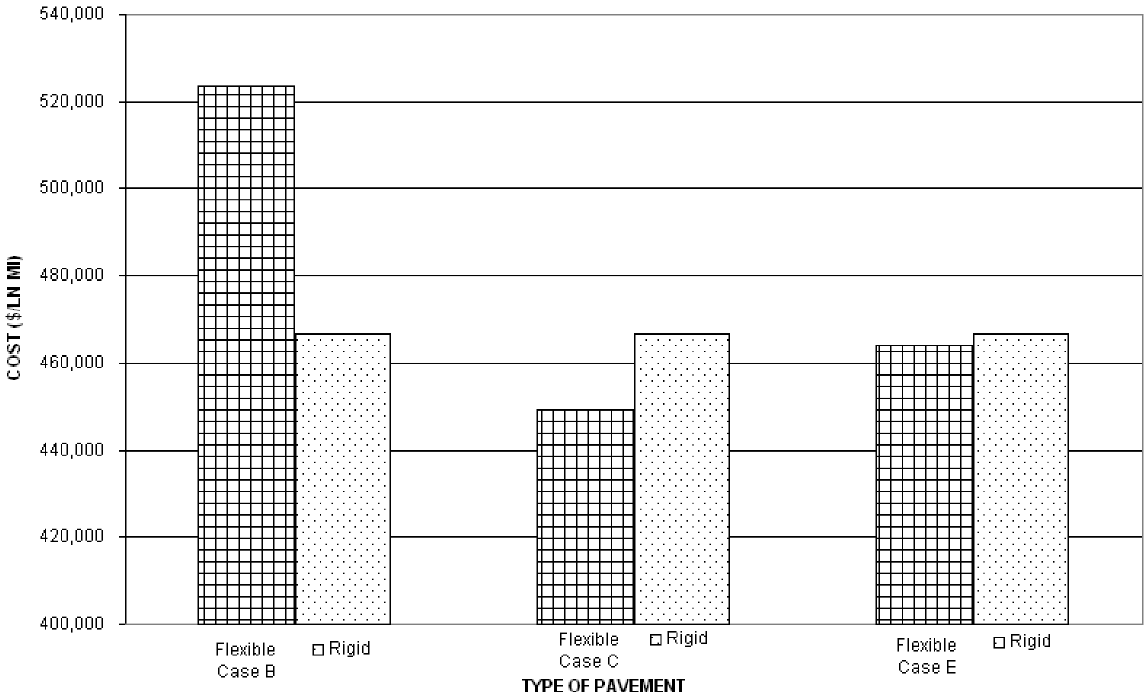


Figure 11. Cost Comparison Flexible vs. Rigid Cases with a 7 Percent Discount Rate.

Life-Cycle Cost Analysis Including User Costs

Four different cases, based on traffic level, were analyzed to study the effects of user cost's on the total life-cycle cost.

The four traffic levels considered in the analysis were:

- Very Low Traffic (1 million ESALs),
  - Initial ADT: 2,000 / Maximum ADT: 3,590
- Low Traffic (5 million ESALs),
  - Initial ADT: 10,000 / Maximum ADT: 17,950
- Intermediate Traffic (15 million ESALs),
  - Initial ADT: 20,000 / Maximum ADT: 35,900
- High Traffic (30 million ESALs).
  - Initial ADT: 55,000 / Maximum ADT: 98,725

The following general information was assumed for all cases:

- good subgrade conditions (15 ksi or 300 pci),
- initial serviceability index / minimum serviceability index: 4.5 / 2.5,
- discount rate: 4 percent, and

- 30- year analysis period.

Road user costs were taken from TxDOT's Memoranda. At the beginning of each year, TxDOT adjusts the value of time that is used in the calculations for determining road user costs. The adjustment is based on the consumer price index (CPI) as it stands in January of the given year. Table 27 shows the user costs for the past 4 years, the one for year 2008 was used in the analysis. These costs were taken from TxDOT's Memorandum to its District Engineers (*44*).

Table 27. TxDOT's User Costs for the Past Four Years.

Year	2005	2006	2007	2008
User Costs ($/vehicle hour)	17.80	18.21	18.81	19.35

The results from the life-cycle cost analysis including using costs for a discount rate of 4 percent are shown in Table 28.

Table 28. RealCost Results Including User Costs.

Case	Time of Day	Present Value Cost ($/lane mile), Discount Rate at 4%					
		Flexible Pavement			Rigid Pavement		
		Agency Cost	User Cost	Total Cost	Agency Cost	User Cost	Total Cost
Very Low Traffic	8 am to 5 pm	281,230	3,580	284,810	445,140	6,700	451,840
Low Traffic	8 am to 5 pm	335,430	31,110	366,540	445,140	29,140	474,280
Intermediate Traffic	8 am to 5 pm	462,080	93,310	555,390	445,140	58,270	503,410
High Traffic	8 am to 5 pm	534,460	299,860	834,320	445,140	296,270	741,410

It is observed from Table 28 that for intermediate and high traffic the rigid pavement design becomes the alternative with the lowest total life-cycle cost.

Sensitivity Analysis

Sensitivity analyses on the following parameters that impact user costs were conducted using RealCost work zone speed limit:

- work zone length,
- number of lanes opened during construction,
- work zone capacity (vehicle per hour per lane),
- queue dissipation capacity,
- maximum queue length,
- traffic distribution,
- work zone duration (days), and
- work zone time.

Work Zone Speed Limit (mph)

Two different speed limits typically used by TxDOT in construction and maintenance of roads were evaluated during the analysis, 45 mph and 55 mph. As might seem reasonable, the higher speed limit, 55 mph, has a lower user cost. However, the difference on average was in the range of 1 percent to 3 percent; therefore, this input was not further analyzed.

Work Zone Length (miles)

Two different zone lengths were analyzed, 3 and 6 miles. However, the difference on average was very small (i.e., keeping everything else constant, the user cost for a 3 mile work zone was $7055 and the user cost for a 6 mile work zone was $7088). Therefore, this input was not further analyzed.

Number of Lanes Opened During Construction and Work Zone Capacity (vphpl)

The research team analyzed how the number of lanes opened to traffic during construction would affect the user costs. The work zone capacity, or number of vehicles per hour per lane, is directly influenced by the number of open lanes.

For this project, the research team analyzed the effect of having one lane opened with a capacity of 1170 vehicles per hour per lane, or two lanes opened with a capacity of 1510 vehicles per hour per lane. These numbers were taken from recommendations given by RealCost User Guide (*43*). This parameter made a significant difference in the user cost when the work is done during the day (8 am to 5 pm); $7055 with one lane open and $130 with two lanes opened. The change in costs due to this parameter for night time work is almost zero.

Queue Dissipation Capacity (vphpl)

This parameter refers to the number of vehicles per hour in queue in each lane during working conditions. The research team analyzed two numbers, 1500 and 2000 vehicles per hour per lane, based on recommendations made by a publication by the U.S. Department of Transportation (*14*).

The lower number, 1500 vphpl, gave a lower user cost, $7055 for working hours from 8 am to 5 pm, as opposed to the 2000 vphpl that resulted in $6145 for the same working time. As can be seen, this input did not greatly affect the user costs.

Maximum Queue Length (miles)

This parameter models the effects of self-imposed detours (traffic exiting from the work zone route still incur some user costs). Queue related user costs, which are based upon queue length, are calculated with this figure instead of the calculated queue length. However, all vehicles, even those that detour, are charged queue costs (*43*).

The research team analyzed two lengths, 5 and 15 miles. The 15 mile queue length gave higher user costs, as expected. The magnitude was not important if the work is done at night, but if the work is done from 8 am to 5 pm, there is a 50 percent reduction on the user costs due to this parameter. That is, the 5 mile queue length resulted in a $3000 user cost whereas the 15 mile queue length gave $7055 for the 8 am to 5 pm working time.

Work Zone Duration (days)

In order to analyze the sensitivity of different parameters with regard to user costs, the research team had to input two different durations in RealCost: the duration of the initial construction, and the duration of the asphalt overlay or concrete patching, depending on the type of pavement. When TxDOT uses alternate bids, the number of days for both flexible and rigid pavement construction is the same; therefore, the research team chose to assume this parameter as zero. This way the user costs given by RealCost were only due to the overlay or patching.

For comparison purposes, a 2-inch overlay was assumed to be done on the flexible pavement during year 15, and two (10 by 12 ft) patches per lane mile were assumed to be the maintenance done on the rigid pavement during year 20. The time it would take a crew to complete the overlay was calculated to be nine days (at a rate of two lane miles per day, working eight hours a day). The time it would take a crew to complete the patching was calculated to be six days (at a rate of two patches per day, assuming the lane that gets the most trucks is the only one being patched). The total length of the project was 6.98 miles.

It is reasonable to say that the longer the duration, the higher the user costs. For example, for a duration of six days with one crew working, the user costs came to be $7055, whereas for nine days the user cost for the same conditions was $10,583. This parameter can be managed depending on the number of crews working at a time. It is safe to assume that the shorter the duration of the work, the better.

Work Zone Time

The research team compared three different work times:

- 8 am to 5 pm (9 hours),
- 7 pm to 7 am (12 hours), and
- 9 pm to 6 am (9 hours).

This parameter was found to be the most influential on user costs. In every case, the nighttime work, especially 9 pm to 6 am gave the lower user cost. It seems almost unreasonable to do any patching or overlaying during daytime.

In order to demonstrate the difference in costs obtained when changing this parameter and keeping every other parameter constant, we cite an example of the user costs given by the different times analyzed:

- 8 am to 5 pm: $ 7000 per lane mile,
- 7 pm to 7 am: $ 170 per lane mile, and
- 9 pm to 6 am: $ 9 per lane mile.

It is of most importance, when using alternate bids for a given project, to take into consideration the time at which the patching or overlaying will be done. This could be the factor that makes the difference between rigid or flexible pavement.

CONCLUDING REMARKS

Concluding remarks from the case studies are as follows:

1. Changing the present serviceability index values while keeping the difference between them the same (i.e., 4.5 to 2.5, and 4.0 to 2.0) does not greatly influence the thickness of the ACP layer in the flexible pavement designs. The influence that the PSI change has on the slab thickness is negligible in the rigid pavement designs (0.1 to 0.2 inches). Based on these results, an initial PSI of 4.5 and a terminal PSI of 2.5 is recommended for flexible and rigid pavements when considered alternate pavement designs.
2. The environmental conditions influence the thickness of the layers for very low traffic (1 million ESALs) cases, but not the rest of the traffic levels. For pavement alternates it is recommended to use the appropriate district values.
3. The better the subgrade condition, the thinner the ACP layer (about ½ to 1 inch).
4. For equivalent designs flexible and rigid pavements should consider equivalent traffic levels to account for the same performance.
5. The 'minimum time to first overlay' has a significant influence on the initial thickness of the ACP layer in FPS-19W flexible pavement designs. TxDOT currently recommends using a minimum time to first overlay of 15 years when pavement alternates are used. However, different times to first overlay were used in the past based on engineering judgment and individual TxDOT districts' experiences with overlays. TxDOT pavement designers have considered a range of 8 years to 20 years for this input when designing pavement alternates. However, based on this analysis, using a 30-year value generates unusually thick initial pavement structures in FPS-19W.
6. TxDOT recommends a modulus of 650 ksi when the ACP layer is 8 inches or more, and 500 ksi for an ACP layer thinner than 8 inches.

7. It is of most importance, when using alternate bids for a given project, to take into consideration the time at which the patching or overlaying will be done. This could be the factor that makes the difference between rigid or flexible pavement.

CHAPTER 5:
GUIDELINES FOR DETERMINING WHEN TO CONSIDER PAVEMENT ALTERNATES

This chapter describes the guidelines with a protocol for determining when to consider pavement alternates. It later proposes a modification to the TxDOT Design Summary Report (*45*), and recommends inputs for life-cycle cost analysis.

The process for determining when pavement alternates should be considered by TxDOT personnel developing plans, specifications, and estimates for new construction or reconstruction projects consists of the following:

- Guidelines for alternate pavement designs. These guidelines were used as the basis for developing the Alternate Pavement Design Analysis Tool. APDAT and the FHWA RealCost software both are developed in Excel to assist users in determining if pavement alternates may be a possibility.
- A modification to the TxDOT Design Summary Report (*45*) that describes when pavement alternates should not be used. The researchers suggest two different options for this modification; although they do not have an opinion as to what option is used.
- Recommended inputs for life-cycle cost analysis.

GUIDELINES FOR ALTERNATE PAVEMENT DESIGNS

Some projects could be candidates for alternate pavement design while others may not be suitable candidates. In order to determine if a particular project is a good candidate, the following general guidelines are presented.

Protocol

The step-by-step process proposed to determine whether or not to include alternate pavement designs in a specific project is proposed as a guideline and is shown in Figure 12.

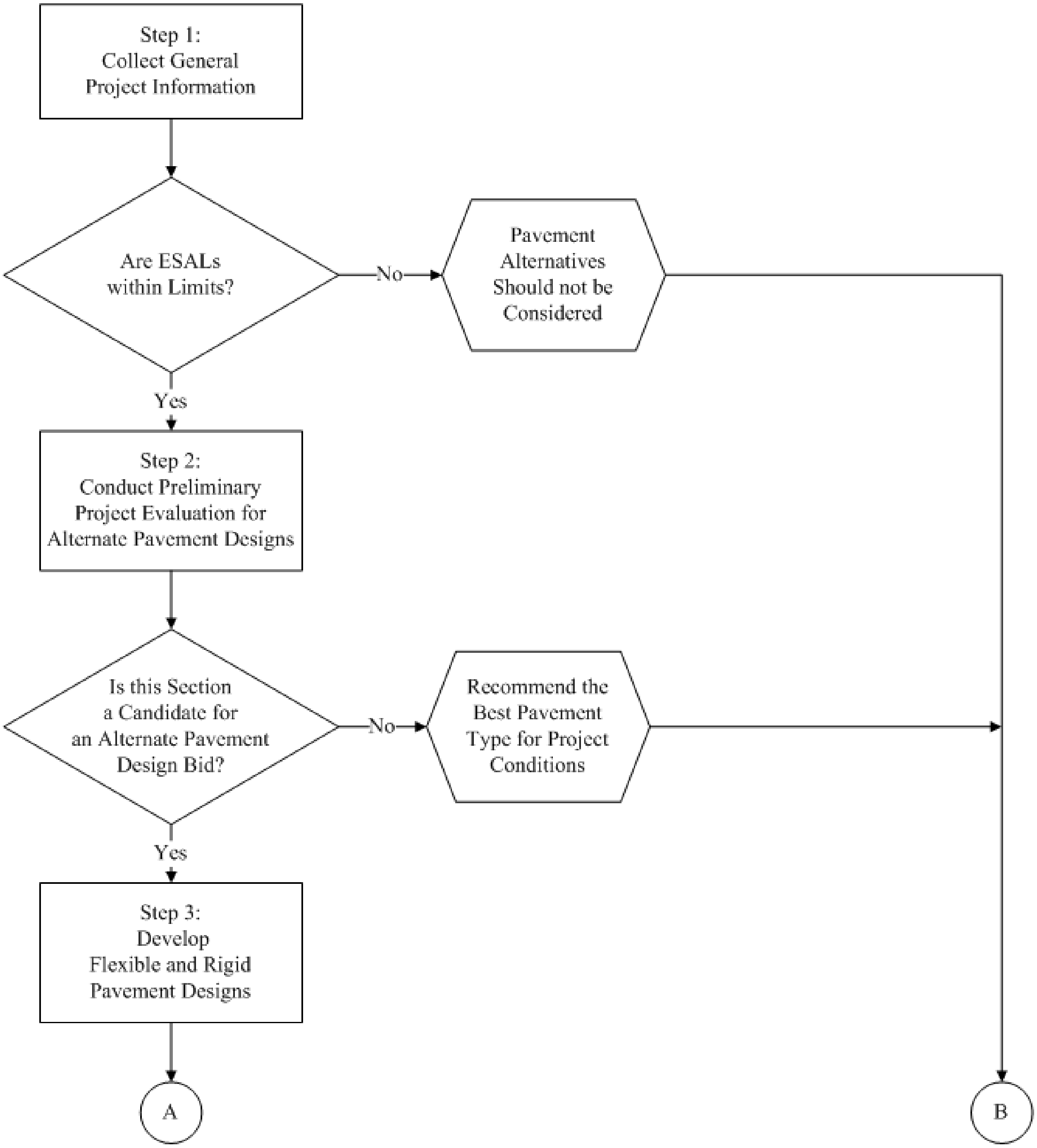


Figure 12. Alternate Pavement Design Analysis Flowchart.

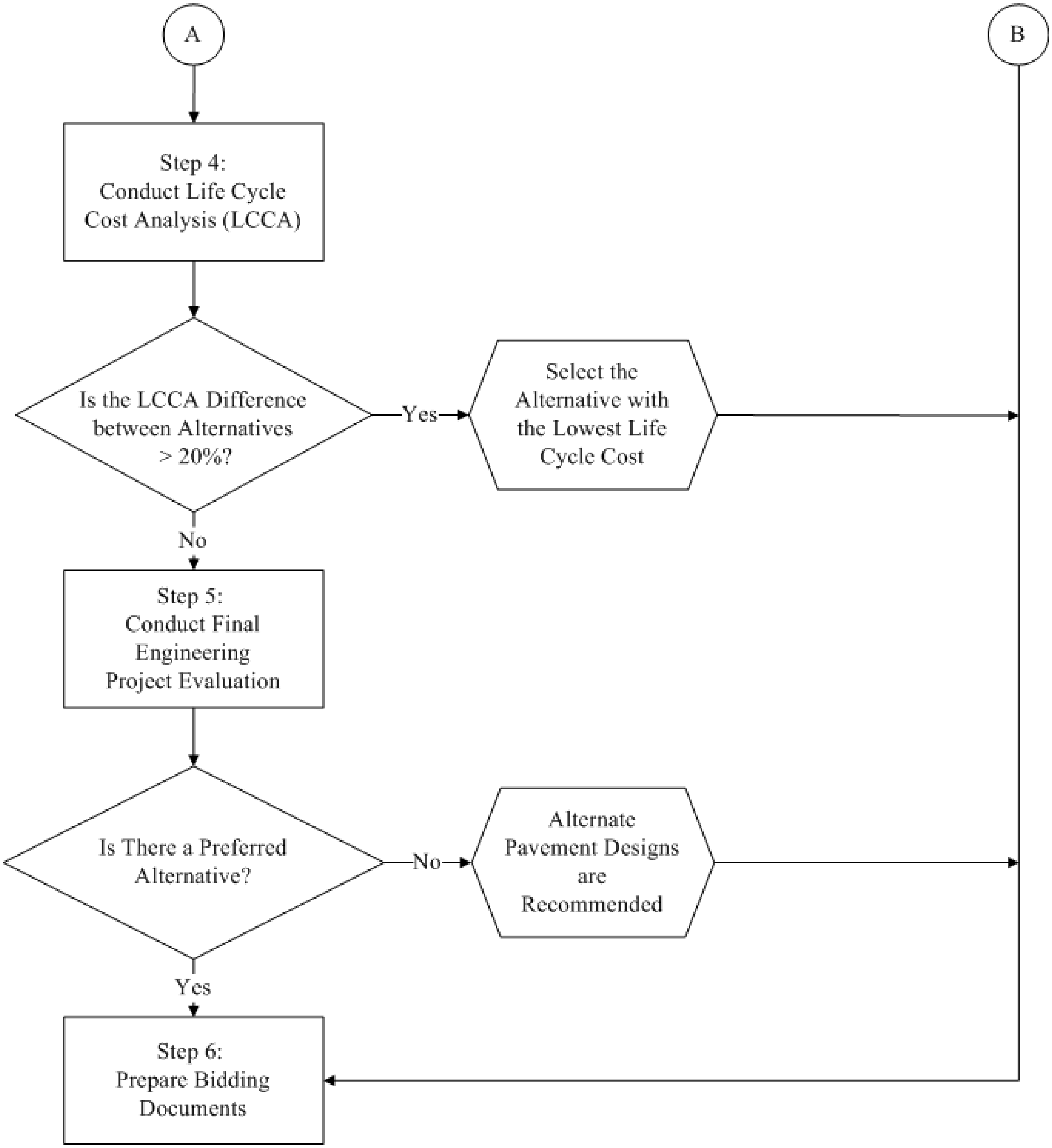


Figure 12. Alternate Pavement Design Analysis Flowchart (Continued).

Step 1: Collect General Project Information

During this step, general information about the project is collected. This includes the name of the project, region, county, district, project size, ESALs. Lower and upper limit ESALs are based on environmental conditions. A default of these limits is provided for each TxDOT district. If the ESALs are outside the districts limits, then pavement alternates should not be considered. In any of these cases, then proceed to Step 6: Prepare Bidding Documents. On the other hand, if the ESALs are within the district's limits then proceed to Step 2.

Step 2: Conduct Preliminary Project Evaluation for Alternate Pavement Designs

A preliminary project evaluation is conducted based on answers provided to seven questions. These questions have been found to be important on earlier TxDOT projects. Each answer is assigned a certain number of points, as shown in parentheses. Based on the answers to these seven questions, a total number of points is calculated to determine if the project is a candidate for alternate pavement designs. These seven questions are:

1. Total lane miles on this project are approximately:
    a. Less than 1 lane mile (0 points)
    b. 1 to 8 lane miles (5 points)
    c. 9 to 20 lane miles (10 points)
    d. More than 20 lane miles (15 points)
2. Construction traffic control difficulties on this project are best described as:
    a. Insignificant (15 points)
    b. Minor (10 points)
    c. Moderate (5 points)
    d. Severe (0 points)
3. The total number of bridge structures on this pavement divided by the pavement length in miles is:
    a. Less than 0.5 (15 points)
    b. 0.51 to 1 (10 points)
    c. 1.01 to 2.0 (5 points)
    d. More than 2.01 (0 points)
4. The total number of driveways on one side of this pavement divided by the pavement length in miles is:
    a. 0 to 5 (15 points)
    b. 6 to 10 (10 points)
    c. 11 to 20 (5 points)
    d. More than 21 (0 points)

5. The estimated total project cost is:
   a. Less than $5 million (5 points)
   b. $5 to $10 million (10 points)
   c. $10 to $20 million (15 points)
   d. Greater than $20 million (20 points)
6. Underground utility issues on this project are best described as:
   a. Insignificant (15 points)
   b. Minor (10 points)
   c. Moderate (5 points)
   d. Severe (0 points)
7. Subgrade issues on this project are best described as:
   a. No significant issues. (15 points)
   b. Issues exist but are believed completely addressed by planned construction treatment. (10 points)
   c. Significant issues exist which may possibly be only partially addressed during project construction. (5 points)
   d. Very significant issues exist which are likely to require additional attention at some point in the future. (0 points)

The recommendation of a project as a candidate for alternate pavement designs is based on the total number of points, as shown in Table 29.

Table 29. Recommendation from Preliminary Project Evaluation.

Points	Recommendation
≥ 90	This project appears to be an excellent candidate for alternate pavement designs. You could proceed to develop flexible and pavement designs.
≥ 75 and < 90	This project appears to be a proper candidate for alternate pavement designs. You could proceed to develop flexible and pavement designs.
≥ 45 and < 75	This project appears to be a possible candidate for alternate pavement designs. You could proceed to develop flexible and pavement designs.
< 45	This project does not appear to be a candidate for alternate pavement designs. You can stop the analysis at this stage.

If the project does not appear to be a candidate for alternate pavement design, then stop the analysis. In this case, the engineer must recommend the best pavement type for the given project and then proceed to Step 6: Prepare Bidding Documents. If the initial recommendation is that the project warrants continued consideration then proceed with the life-cycle cost analysis process and proceed to Step 3.

Step 3: Develop Flexible and Rigid Pavement Designs

Based on the recommendation given in Step 2, Flexible and Rigid pavement alternate designs are developed at this time.

Step 4: Conduct Life-Cycle Cost Analysis (LCCA)

After developing the Flexible and Rigid Pavement Designs, an LCCA of both alternatives is conducted. This is achieved by inputting project information. If the LCCA difference between the alternatives is more than 20 percent, the engineer should select the alternative with the lowest life-cycle cost and then proceed to Step 6: Prepare Bidding Documents. If the LCCA difference between the alternatives is less than 20 percent alternate pavement design is recommended for the bidding process and then proceed to Step 5.

Step 5: Conduct Final Engineering Project Evaluation

In any project, a final engineering evaluation must be done before selecting the pavement type alternative. If there is a preferred alternative for any reason, the reason should be documented and the preferred pavement type selected. If there is no preferred alternative, alternate pavement designs are recommended and then proceed to Step 6.

Step 6: Prepare Bidding Documents

The last step of the process is to prepare the bidding documents based on recommendations from Steps 1 through 5.

The step by step process described above has been programmed in a user friendly tool. The Alternate Pavement Design Analysis Tool (APDAT) Quick Start Guide is included in Appendix B.

PROPOSED TXDOT DSR MODIFICATION

The researchers propose two different options for modifying the TxDOT DSR. Both involve inserting a new section C on page 13, Proposed Pavement Structure Elements, on the DSR.

First Option

The first option consists of the following text:

The following characteristics make a pavement unsuitable for offering alternative pavement designs in the plans.

- This is a pavement widening project.
- The project does not involve new construction or reconstruction.
- The pavement is less than 500 feet in length.
- The pavement is less than 5 miles in length, and both connecting pavements are either rigid or flexible pavements.
- There are areas of the pavement where truck traffic will be stationary for long periods of time.
- The projected one-way average daily truck traffic is either less than 300 or greater than 2,000.

If this pavement does not include any of the above characteristics, use APDAT to further explore offering alternative pavement designs. Results of this analysis were:

- This pavement appears to be an excellent candidate for alternative pavement designs.
- This pavement appears to be a proper candidate for alternative pavement designs.
- This pavement appears to be a possible candidate for alternative pavement designs.
- This pavement does not appear to be a candidate for alternative pavement designs.

Second Option

The second option consists of the following text:

The following characteristics make a pavement unsuitable for offering alternative pavement designs in the plans.

- This is a pavement widening project.

- The project does not involve new construction or reconstruction.
- The pavement is less than 500 feet in length.
- The pavement is less than 5 miles in length and both connecting pavements are either rigid or flexible pavements.
- There are areas of the pavement where truck traffic will be stationary for long periods of time.
- The concrete pavement thickness calculated for a 30-year design is less than 8 inches or 12 inches and greater.

If this pavement does not include any of the above characteristics, use APDAT to further explore offering alternative pavement designs. Results of this analysis were:

- This pavement appears to be an excellent candidate for alternative pavement designs.
- This pavement appears to be a proper candidate for alternative pavement designs.
- This pavement appears to be a possible candidate for alternative pavement designs.
- This pavement does not appear to be a candidate for alternative pavement designs.

Explanation of Options

The first five characteristics for both options were determined from the interviews with TxDOT personnel described in Chapter 3.

The sixth characteristic for both options was developed based on a request from TxDOT administration to suggest limits based on traffic values where pavement alternates should not be considered.

For option 1, the lower limit of 300 trucks per day and upper limit of 2,000 trucks per day are suggested based on analysis of truck traffic data for mainlane sections contained in TxDOT's Pavement Management Information System data for Fiscal Year 2008. Frontage road sections are not included in the analysis. Figure 13 shows the result of the analysis of annual daily truck traffic for the mainlane PMIS sections sorted by pavement type.

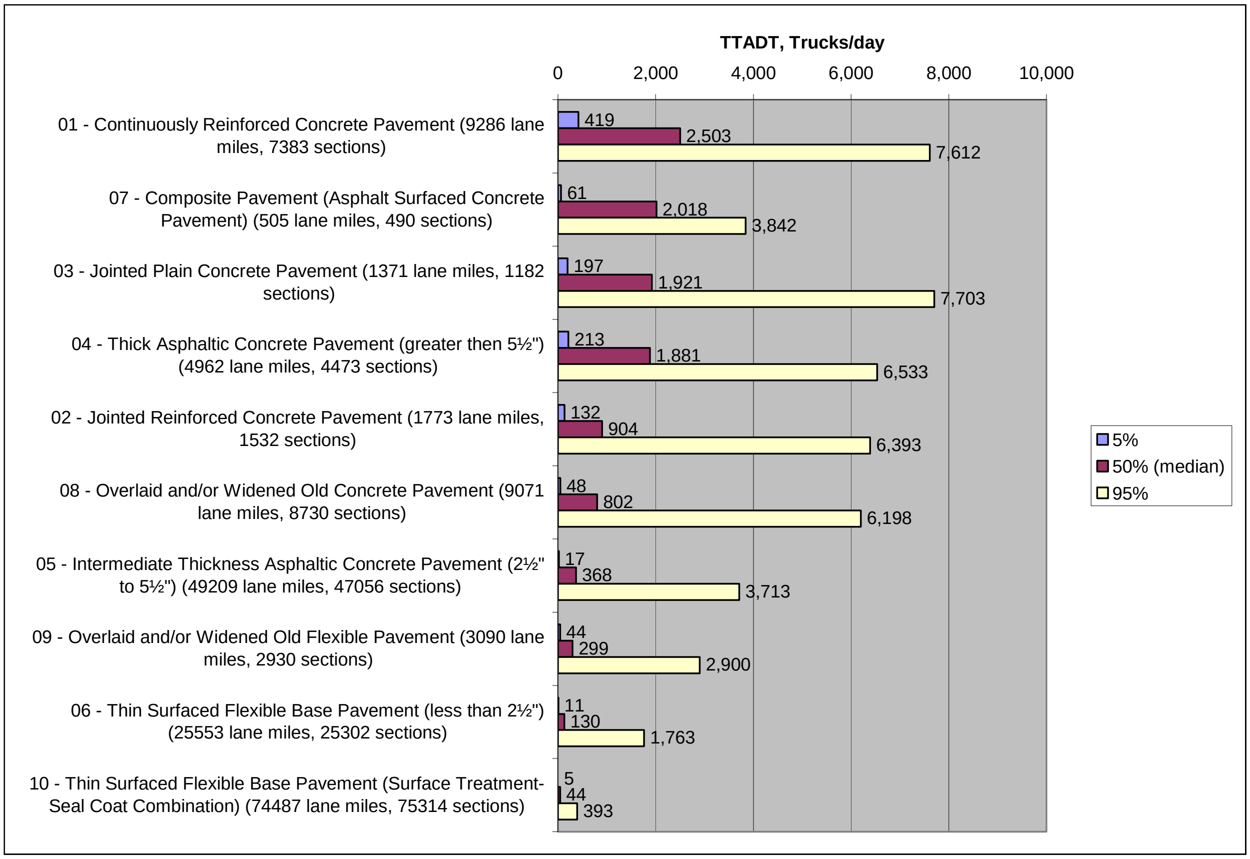


Figure 13. Analysis of One-way Daily Truck Traffic Values in the Fiscal Year 2008 PMIS Database for Mainlane Sections.

As Figure 13 shows, the median value is 1,921 trucks per day in one direction for Pavement Type 3 (Jointed Plain Concrete Pavement, or JPCP) and 2,503 trucks per day in one direction for Pavement Type 1 (Continuously Reinforced Concrete Pavement, or CRCP). In addition, the median value for Pavement Type 5 (Intermediate Thickness Asphaltic Concrete Pavement) is 368 vehicles per day in one direction. Finally, 5 percent of the CRCP sections have one direction daily truck traffic values of 419 or less; and 5 percent of the JPCP sections have one direction daily truck traffic values of 213 or less. The researchers suggest the limits above based on these observations from the analysis.

Further analysis of the truck traffic data in the Fiscal Year 2008 PMIS database indicates that 65.1 percent of the Fiscal Year 2008 PMIS sections have daily truck traffic values of 300 or less; and 10.43 percent have daily truck traffic values greater than 2,000. This would result in 24.42 percent of the sections eligible for pavement alternates. Figure 14, Figure 15, and Figure

16 are maps showing the sections based on the limits stated above. Table 30 shows the cumulative percentage of PMIS sections for specified one direction daily truck traffic values.

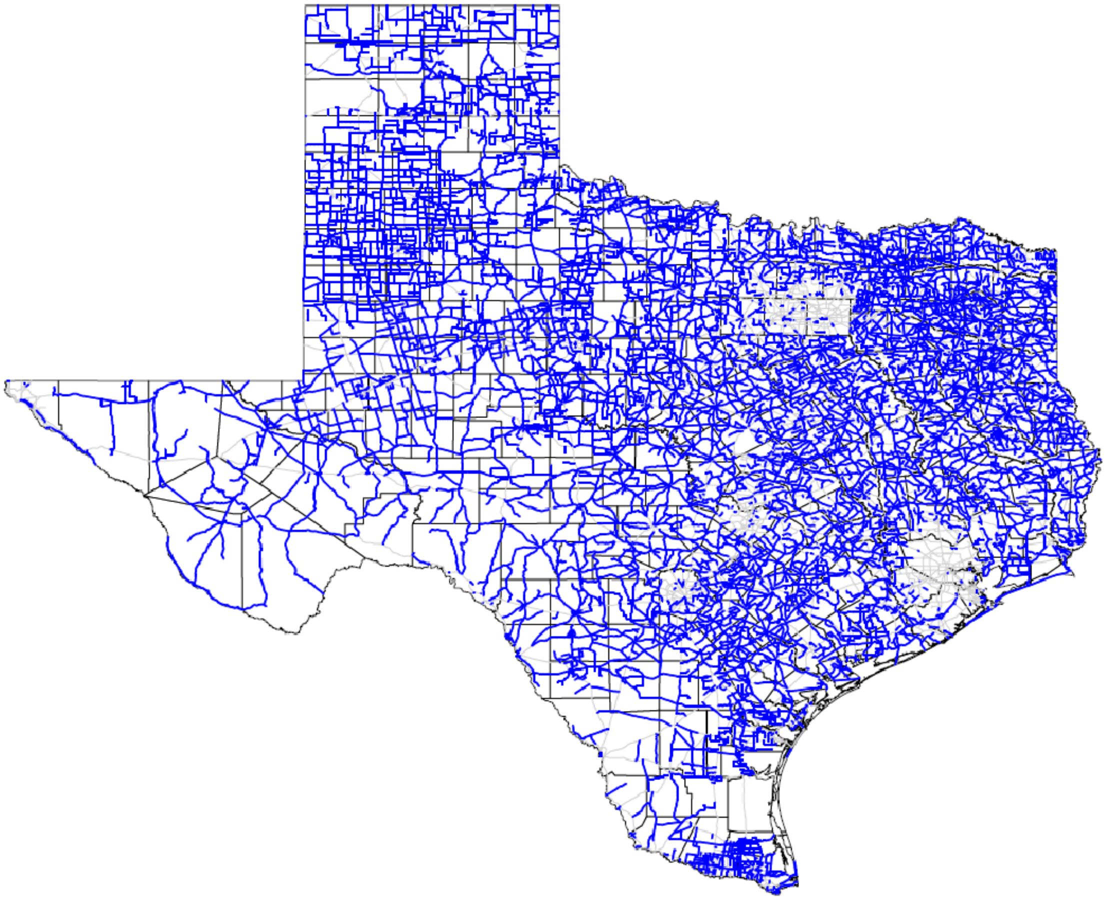


Figure 14. Fiscal Year 2008 PMIS Sections with One-way Daily Truck Traffic Values of 300 or Below.

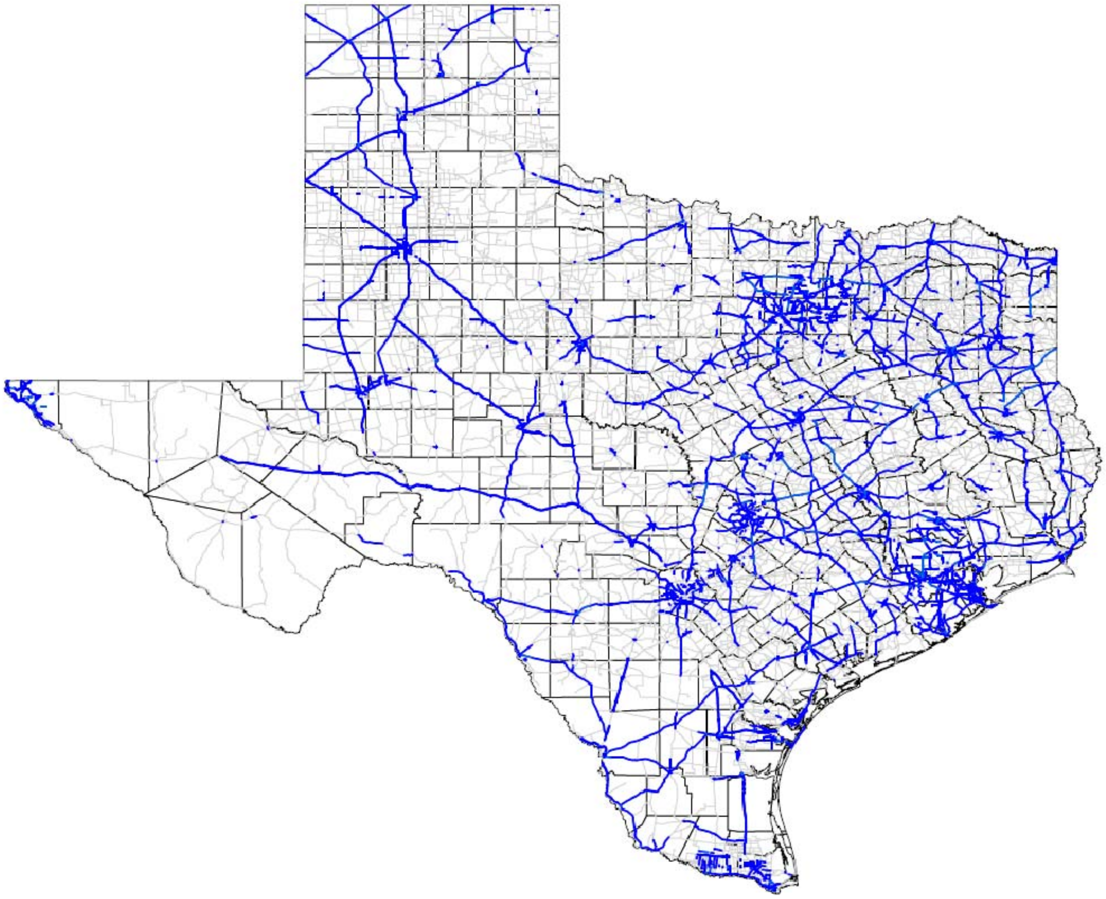


Figure 15. Fiscal Year 2008 PMIS Sections with One-way Daily Truck Traffic Values between 300 and 2,000.

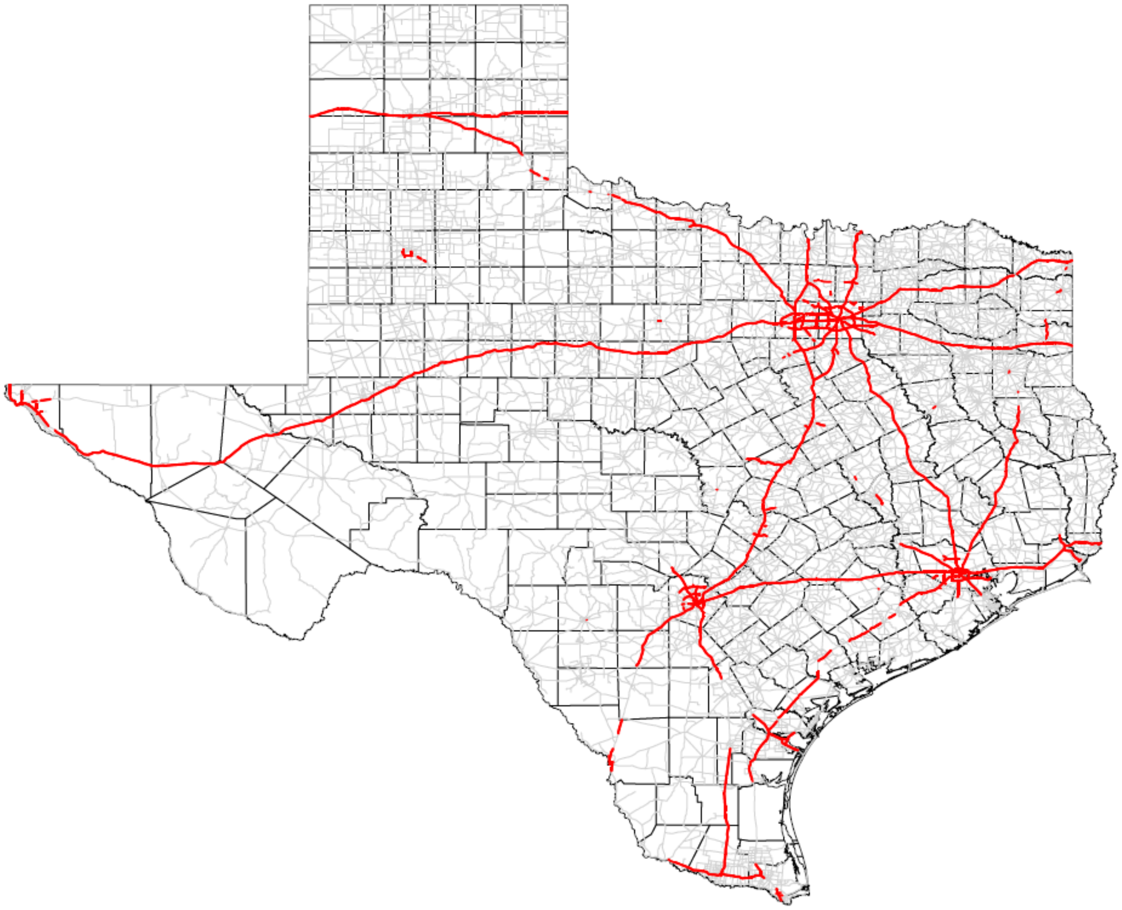


Figure 16. Fiscal Year 2008 PMIS Sections with One-way Daily Truck Traffic Values of 2,000 or above.

Table 30. One Direction Daily Truck Traffic Value Percentages Based on PMIS Data from Fiscal Year 2008.

One Direction Daily Truck Traffic (DTT)	Percent Less than or equal to DTT (%)	Percent Greater Than DTT (%)
50	30.25	69.75
100	44.20	55.80
200	57.15	42.85
300	65.15	34.85
400	70.59	29.41
500	74.34	25.66
600	77.20	22.80
700	79.28	20.72
800	81.01	18.99
900	82.38	17.62
1,000	83.51	16.49
1,100	84.32	15.68
1,200	84.94	15.06
1,300	85.47	14.53
1,400	86.53	13.47
1,500	87.34	12.66
1,600	87.98	12.02
1,700	88.41	11.59
1,800	88.98	11.02
1,900	89.23	10.77
2,000	89.57	10.43
2,100	90.07	9.93
2,200	90.50	9.50
2,300	90.87	9.13
2,400	91.34	8.66
2,500	91.58	8.42
2,600	91.81	8.19
2,700	92.07	7.93
2,800	92.30	7.70
2,900	92.53	7.47
3,000	92.75	7.25
4,000	95.12	4.88
5,000	97.00	3.00

For option 2, the concrete pavement thickness limits indicated in the sixth characteristic were based on the following observations and analyses.

To determine estimated concrete pavement thickness for mainlane Fiscal Year 2008 PMIS sections, the researchers used the 20-year projected one-way cumulative 18 kip equivalent single axle load values (18 KESALS) contained in the Fiscal Year 2008 PMIS database (the database does not include values for frontage roads). Since TxDOT concrete pavement designs are based on a 30-year analysis period, the researchers assumed that the 20-year projected values in the Fiscal Year 2008 PMIS database are 62 percent of the 30-year projected values. In addition, since the PMIS database included flexible 18 KESAL projections, the researchers assumed that the flexible 18 KESAL values are 70 percent of the rigid 18 KESAL values. These assumptions were based on traffic projections provided by TxDOT's Transportation Planning and Programming Division for IH 35 in Bell County and SH 16 in Palo Pinto County, as well as observations made by the research supervisor concerning such traffic projections.

The researchers then generated the 30-year rigid 18 KESAL values for concrete pavement thicknesses between 7 and 15 inches using the 1993 AASHTO Guide and the recommended inputs from TxDOT's Pavement Design Manual (*29*). In particular, for the drainage coefficient, the researchers used the annual rainfall at or near the district office for each TxDOT district (the rainfall information was obtained from http://countrystudies.us/united-states/weather/texas/). In addition, the researchers used a load transfer coefficient of 2.9. Table 31 shows the resulting percentages as a result of thickness.

Table 32 shows the 18 KESALs as a function of concrete pavement thickness from 7 to 15 inches and for three coefficients of drainage (0.91 would generally be used for concrete designs in the Beaumont area; 1.16 would be used for concrete designs in the El Paso area).

Table 31. Fiscal Year 2008 PMIS Estimated Mainlane Section Percentages Based on Calculated Concrete Depth from 20-Year Projected 18 KESAL Data.

Concrete Depth (in)	Percent Greater	Percent Less or Equal
7.0	46.95	53.05
7.5	40.44	59.56
8.0	34.08	65.92
9.0	23.62	76.38
10.0	16.47	83.53
11.0	11.19	88.81
11.5	8.91	91.09
12.0	7.03	92.97
12.5	4.98	95.02
13.0	3.76	96.24
13.5	2.24	97.76
14.0	1.09	98.91
14.5	0.30	99.70
15.0	0.01	99.99

Table 32. Thirty Year Rigid 18 KESALs Based on Concrete Depth and Coefficient of Drainage.

Concrete	Coefficient of Drainage		
Depth, in.	0.91	1.00	1.16
7.0	801,367	1,106,395	1,838,045
7.5	1,157,678	1,598,329	2,655,292
8.0	1,658,945	2,290,396	3,805,017
9.0	3,307,038	4,565,805	7,585,145
10.0	6,300,847	8,699,163	14,451,854
11.0	11,470,661	15,836,783	26,309,530
11.5	15,230,628	21,027,898	34,933,528
12.0	20,022,550	27,643,812	45,924,460
12.5	26,075,754	36,001,032	59,808,312
13.0	33,659,504	46,471,404	77,202,592
13.5	43,088,112	59,488,938	98,828,488
14.0	54,726,756	75,557,652	125,523,312
14.5	68,996,968	95,259,601	158,253,999
15.0	86,384,192	119,265,004	198,133,979

The lower limit of 8 inches was based on the fact that the current TxDOT standards for CRCP and JPCP do not specify designs for thicknesses less than 8 inches. The researchers estimated that about 66 percent of the mainlane Fiscal Year 2008 PMIS sections would require concrete pavement thicknesses of 8 inches or less.

The upper limit of 12 inches was based on an observation that, according to the analysis of 18 KESAL data Fiscal Year 2008 PMIS database, approximately 7 percent of the PMIS sections would require concrete pavement thicknesses of 12 inches or greater. This would result in approximately 27 percent of the PMIS sections eligible for pavement alternates, which is similar to the value of 24.43 percent for option 1. The 18 KESAL limits for concrete pavement thicknesses of 8 inches and 12 inches are included in the APDAT worksheet for each district as well as the drainage coefficients used in the analysis.

These limits are suggested as initial guidelines in determining what projects may be candidates for pavement alternates. These limits may need adjustment as TxDOT personnel gain experience in the pavement alternates process. The researchers suggest adjusting the lower limits shown above (such as a lower TTADT limit of 600 or a minimum concrete pavement thickness of 9 inches) if TxDOT personnel decide to reduce the percentage of roadways that could be candidates for alternates.

RECOMMENDED INPUTS FOR LIFE-CYCLE COST ANALYSIS

Interest Rate

Many states currently use 4 percent in their life-cycle cost analysis procedures. However, the researchers recommend that TxDOT establish an appropriate interest rate based on current financial data.

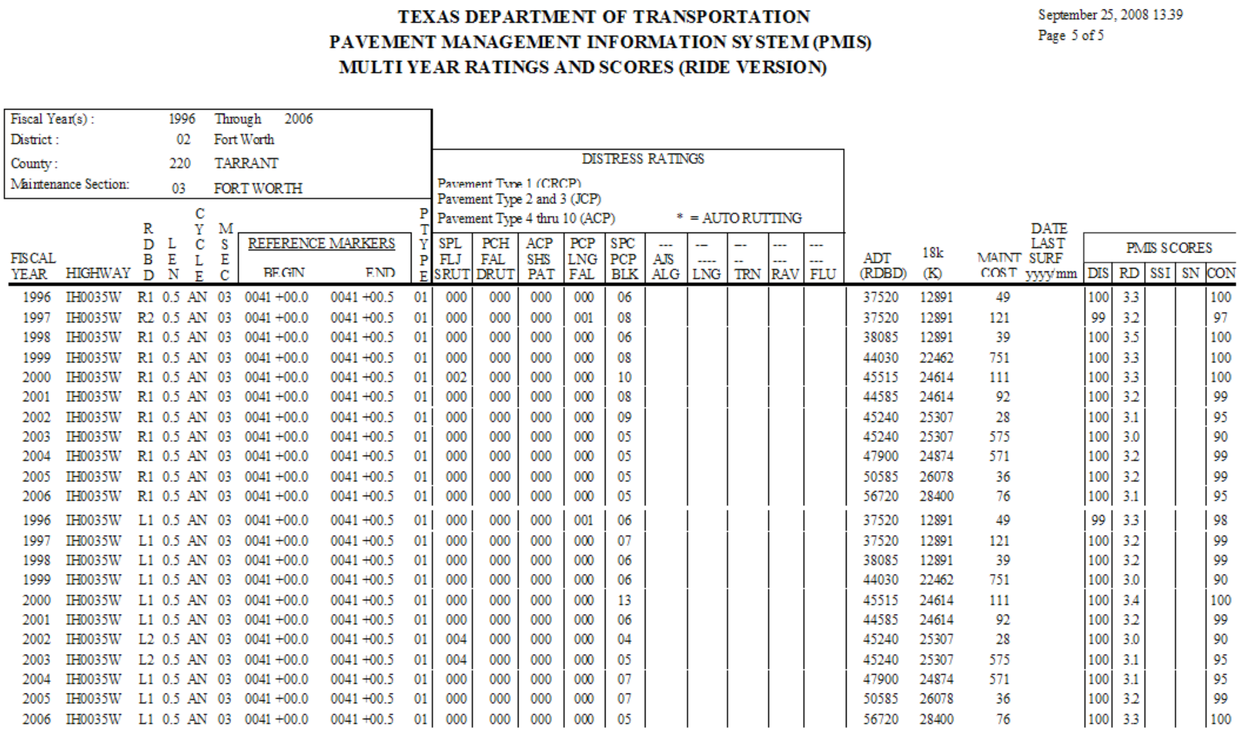
Initial Construction Cost

For initial construction costs, the designers should use thicknesses generated for flexible and rigid pavement designs using the recommended design input values developed by TxDOT that were discussed in Chapter 3. Afterward those thicknesses need to be multiplied by the appropriate unit bid prices for the pavement layers and generate a total cost per square yard. This total cost can also be generated using the APDAT worksheet described earlier in this chapter.

Routine Maintenance Cost

For routine maintenance costs, the researchers recommend consulting with appropriate district maintenance personnel and the District Pavement Engineer as to appropriate costs. The researchers analyzed the maintenance costs contained in the Fiscal Year 2008 PMIS database and included it in a separate worksheet. The data in this worksheet can be used as a basis for discussion as to the appropriate values used. This data is separated by district and by pavement type.

Maintenance costs, pavement scores, distresses, patching, ADT, and other information is also available in the PMIS Multi-Year Ratings and Scores Report available from the TxDOT PMIS mainframe or from the MapZapper program. The PMIS database contains maintenance costs starting in FY 1996 that were obtained from the TxDOT Maintenance Management Information System database. Figure 17 shows the report with data from IH 35W in the Fort Worth District. As can be seen in the figure, the rows in the report are sorted by Fiscal Year, so changes in maintenance costs, pavement scores, patching, ADT, and so on can be identified.



TEXAS DEPARTMENT OF TRANSPORTATION
PAVEMENT MANAGEMENT INFORMATION SYSTEM (PMIS)
MULTI YEAR RATINGS AND SCORES (RIDE VERSION)

September 25, 2008 13:39
Page 5 of 5

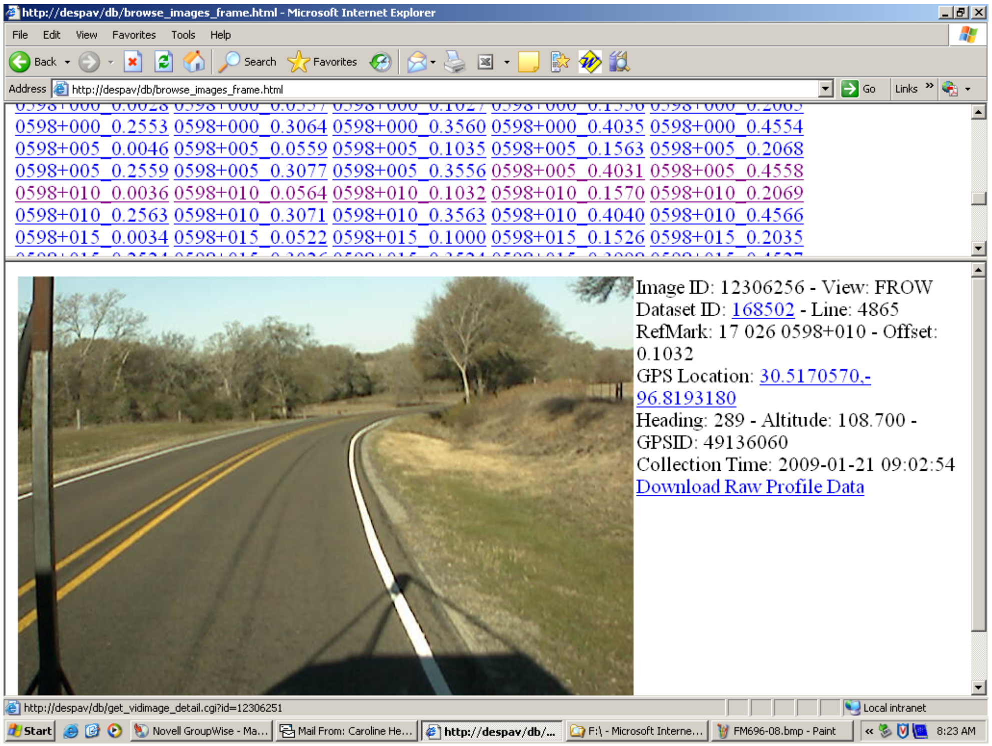
Fiscal Year(s) :	1996	Through 2006
District :	02	Fort Worth
County :	220	TARRANT
Maintenance Section:	03	FORT WORTH

DISTRESS RATINGS
Pavement Type 1 (CRCP)
Pavement Type 2 and 3 (JCP)
Pavement Type 4 thru 10 (ACP) * = AUTO RUTTING

						REFERENCE MARKERS			DISTRESS RATINGS														PMIS SCORES				
FISCAL YEAR	HIGHWAY	RDBD	LEN	CYCLE	MSEC	BEGIN	END	PTYPE	SPL FLJ SRUT	PCH FAL DRUT	ACP SHS PAT	PCP LNG FAL	SPC PCP BLK	--- AJS ALG	--- ---- LNG	--- -- TRN	--- --- RAV	--- --- FLU	ADT (RDBD)	18k (K)	MAINT COST	DATE LAST SURF yyyy/mm	DIS	RD	SSI	SN	CON
1996	IH0035W	R1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	06						37520	12891	49		100	3.3			100
1997	IH0035W	R2	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	001	08						37520	12891	121		99	3.2			97
1998	IH0035W	R1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	06						38085	12891	39		100	3.5			100
1999	IH0035W	R1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	08						44030	22462	751		100	3.3			100
2000	IH0035W	R1	0.5	AN	03	0041 +00.0	0041 +00.5	01	002	000	000	000	10						45515	24614	111		100	3.3			100
2001	IH0035W	R1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	08						44585	24614	92		100	3.2			99
2002	IH0035W	R1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	09						45240	25307	28		100	3.1			95
2003	IH0035W	R1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	05						45240	25307	575		100	3.0			90
2004	IH0035W	R1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	05						47900	24874	571		100	3.2			99
2005	IH0035W	R1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	05						50585	26078	36		100	3.2			99
2006	IH0035W	R1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	05						56720	28400	76		100	3.1			95
1996	IH0035W	L1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	001	06						37520	12891	49		99	3.3			98
1997	IH0035W	L1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	07						37520	12891	121		100	3.2			99
1998	IH0035W	L1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	06						38085	12891	39		100	3.2			99
1999	IH0035W	L1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	06						44030	22462	751		100	3.0			90
2000	IH0035W	L1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	13						45515	24614	111		100	3.4			100
2001	IH0035W	L1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	06						44585	24614	92		100	3.2			99
2002	IH0035W	L2	0.5	AN	03	0041 +00.0	0041 +00.5	01	004	000	000	000	04						45240	25307	28		100	3.0			90
2003	IH0035W	L2	0.5	AN	03	0041 +00.0	0041 +00.5	01	004	000	000	000	05						45240	25307	575		100	3.1			95
2004	IH0035W	L1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	07						47900	24874	571		100	3.1			95
2005	IH0035W	L1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	07						50585	26078	36		100	3.2			99
2006	IH0035W	L1	0.5	AN	03	0041 +00.0	0041 +00.5	01	000	000	000	000	05						56720	28400	76		100	3.3			100

Figure 17. TxDOT PMIS Multi-Year Ratings and Scores Report.

In addition, TxDOT maintains a web site that displays photos taken from cameras mounted in TxDOT's profiler vehicles. These photos are cataloged by Fiscal Year (from 2003 to the present), roadway designation, and reference marker location. The web page is accessible through the TxDOT intranet at http://despav/db/browse_images_frame.html. Figure 18 is a screenshot from this web page. These photos may help in determining if the information from TxDOT's PMIS is representative of roadway conditions.



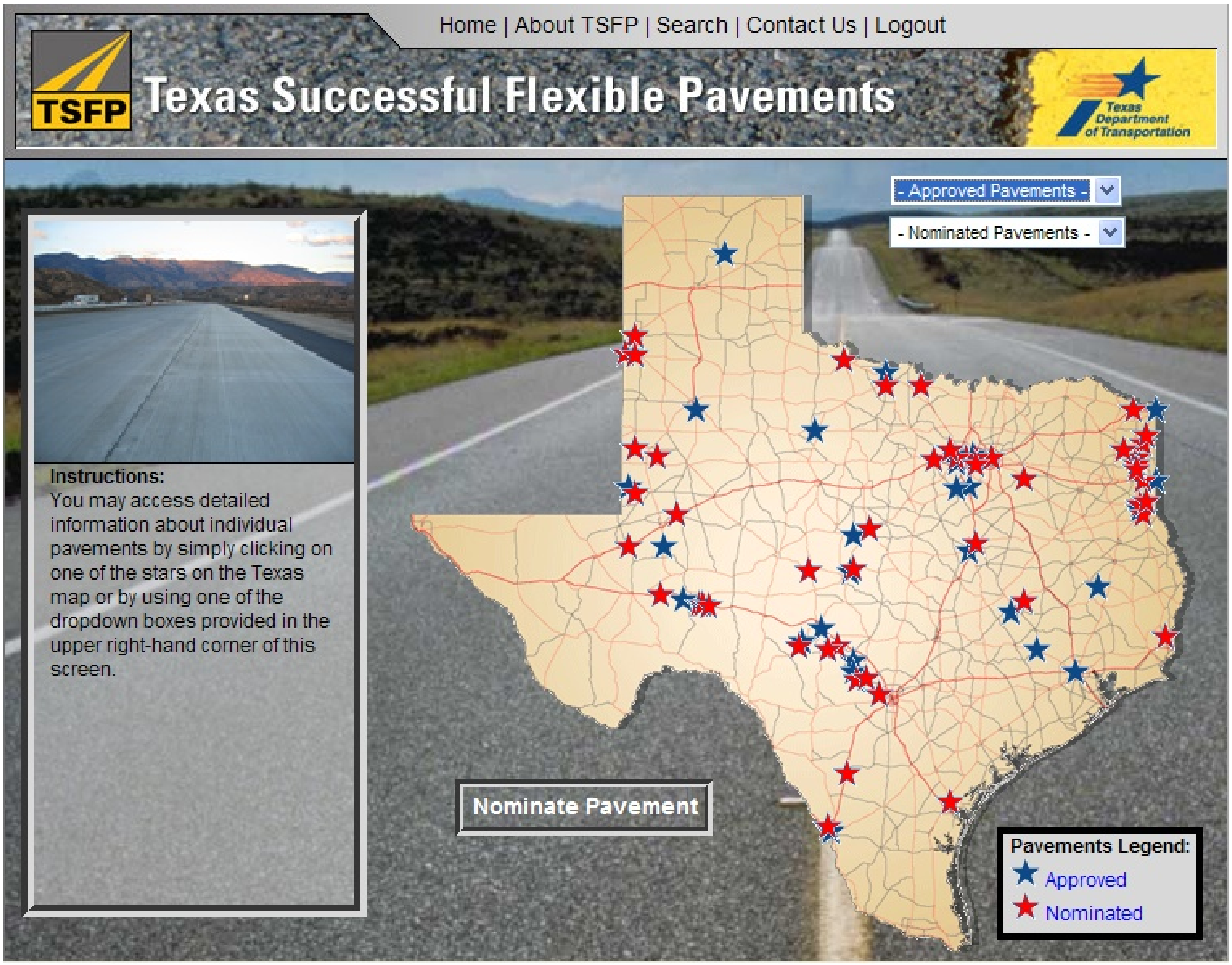
0598+000_0.2553 0598+000_0.3064 0598+000_0.3560 0598+000_0.4035 0598+000_0.4554
0598+005_0.0046 0598+005_0.0559 0598+005_0.1035 0598+005_0.1563 0598+005_0.2068
0598+005_0.2559 0598+005_0.3077 0598+005_0.3556 0598+005_0.4031 0598+005_0.4558
0598+010_0.0036 0598+010_0.0564 0598+010_0.1032 0598+010_0.1570 0598+010_0.2069
0598+010_0.2563 0598+010_0.3071 0598+010_0.3563 0598+010_0.4040 0598+010_0.4566
0598+015_0.0034 0598+015_0.0522 0598+015_0.1000 0598+015_0.1526 0598+015_0.2035

Image ID: 12306256 - View: FROW
Dataset ID: 168502 - Line: 4865
RefMark: 17 026 0598+010 - Offset: 0.1032
GPS Location: 30.5170570,-96.8193180
Heading: 289 - Altitude: 108.700 - GPSID: 49136060
Collection Time: 2009-01-21 09:02:54
Download Raw Profile Data

Figure 18. Screenshot from TxDOT's Pavement Photos Webpage.

Future Overlays, Seal Coats, or Other Surfacings

For timing and costs related to future asphalt concrete pavement overlays, seal coats, or other surfacings, the researchers recommend consulting with appropriate district personnel and collecting data on flexible pavements that are at least 20 years old and have performed well. As mentioned earlier, maintenance costs, pavement scores, distresses, patching, ADT, and other information are also available in the PMIS Multi-Year Ratings and Scores Report available from the PMIS mainframe or from the MapZapper program. In addition, the TxDOT pavement photos web page mentioned earlier may be helpful when determining if the PMIS information reflects actual pavement conditions. The Successful Flexible Pavements Database web site at http://tsfp.tamu.edu/ has useful information for exceptionally well-performing pavement sections located in the majority of districts as shown in Figure 19.



Instructions:
You may access detailed information about individual pavements by simply clicking on one of the stars on the Texas map or by using one of the dropdown boxes provided in the upper right-hand corner of this screen.

Figure 19. Screenshot from the Texas Successful Flexible Pavements Database Showing a Map of Sections Contained in the Database.

As indicated in earlier chapters, the timing of such treatments may vary depending on the district. The effects of inflation should be considered for estimating such costs if possible. The timing and costs are inputs in the APDAT worksheet described earlier in this chapter. The researchers made the following observations concerning the timing of such overlays:

- The project's research supervisor (who was TxDOT's Fort Worth District Pavement Engineer) noted that ACP surfaces in the Fort Worth District with Surface Aggregate Class "B" aggregates usually needed seal coats or microsurfacings between eight and 12 years after they were placed. However, he also noted that ACP surfaces with Surface Aggregate Class "A" aggregates may have service lives between 15 to 20 years without requiring major maintenance.

- Waco District personnel noted that ACP surfaces in their district have service lives between 12 and 15 years.
- San Antonio District personnel indicated that usually their ACP surfaces last for at least eight years in the southern part of the district and 10 years in the northern part before surface oxidation becomes a significant problem; the district then usually places seal coats on those oxidized surfaces.
- The TxDOT surface aggregate selection form indicates that a surface design life between three and seven years relates to a moderate friction demand and a surface design life greater than seven years relates to a high friction demand. TxDOT Surface Aggregate Class A aggregates are considered to provide higher skid resistance properties than Classes B or C, so if an overall high friction demand is indicated from the form, then Class A should be used. These observations should be considered in timing of future overlays, seal coats, or other surfacings.

Future Patching for Rigid Pavements

For timing and costs related to future patching for rigid pavements, the researchers also recommend consulting with appropriate district personnel. For past performance, the researchers recommend that district personnel obtain patching and age information for concrete pavement projects that are at least 20 years old, have performed well, and used stabilized bases underneath the concrete (i.e., 4 inches of ACP, or 1 inch of ACP over 6 inches of cement stabilized base). If a district does not have a significant amount of concrete pavement or sections that meet the above criteria, the researchers recommend using data from nearby districts. Almost all rigid pavement projects constructed since 1985 use stabilized bases (this is when TxDOT began requiring the use of stabilized bases). As mentioned earlier, maintenance costs, pavement scores, distresses, patching, ADT, and other information are also available in the PMIS Multi-Year Ratings and Scores Report available from the PMIS mainframe or from the MapZapper program. In addition, the TxDOT pavement photos webpage mentioned earlier may be helpful when determining if the PMIS information reflects actual pavement conditions.

The researchers noted that, according to statewide PMIS data from 1997 to 2008, the average number of patches per PMIS section for CRCP has declined, as indicated in Table 33. One patch is defined in PMIS as having a length between 12 inches and 10 feet (patch width is not considered). So, for example, a patch that is 15 feet long is actually counted as two patches in PMIS. In addition, according to Fiscal Year 2008 PMIS data, 85.8 percent of the CRCP sections had no asphalt concrete (AC) or Portland cement concrete patches as shown in Table 34. Section ages cannot be determined from the PMIS database, however. Table 33 shows the CRCP patch information sorted by the number of CRCP roadbed miles per district. Not all districts have significant amounts of CRCP (Houston has 36.7 percent of the total state CRCP roadbed miles). In addition, some districts show rather high patch per mile values, which may indicate that those sections are either very old or have not performed well due to issues such as spalling or unstabilized bases.The researchers did obtain project information from the Rigid Pavement Database for CRCP projects built between 1984 and 1991. A total of 31 sections were identified. However, 23 sections were in the Houston District. San Antonio had four sections, Lubbock had two sections, Fort Worth had one section, and Amarillo had one section. Data from these projects may be of benefit for those particular districts, but any observations of patching timing from this data would be biased toward the Houston District. As stated earlier, the researchers recommend using data from sections that are at least 20 years old, have performed well, and used stabilized bases.

Table 33. Number of CRCP Patches per Section from PMIS Data.

Year	No. Sections	AC Patches	PCC Patches	Total Patches	Average Patch/Section
1997	5493	254	6337	6591	1.20
1998	5525	340	5815	6155	1.11
1999	5844	649	7204	7853	1.34
2000	6759	352	7673	8025	1.19
2001	6824	1025	7654	8679	1.27
2002	6954	838	8928	9766	1.40
2003	7146	589	8327	8916	1.25
2004	7585	392	9317	9709	1.28
2005	7906	248	7513	7761	0.98
2006	8079	429	7497	7926	0.98
2007	8361	281	7422	7703	0.92
2008	8990	227	6906	7133	0.79

Table 34. Cumulative Frequency CRCP Patches per Mile - Fiscal Year 2008 PMIS Data.

Percent	Cumulative Frequency, Patches/PMIS Section
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	0
85	0
90	2
95	5
96	6
97	8
98	11
99	17
99.5	23

Table 35. CRCP Patch Information by District.

District Number	District Name	Total Number of Patches	Roadbed Miles CRCP	Average Number of Patches Per Roadbed Mile	Percent of Sections with No Patches (%)
12	Houston	2272	1467.2	1.55	87.50
2	Fort Worth	972	627.9	1.55	86.26
18	Dallas	572	512.1	1.12	87.52
24	El Paso	343	346.2	0.99	86.53
5	Lubbock	1012	204.6	4.95	74.03
4	Amarillo	274	189.5	1.45	81.63
14	Austin	0	155.9	0.00	100.00
3	Wichita Falls	417	137.3	3.04	78.96
20	Beaumont	412	65.1	6.33	71.71
1	Paris	476	64.4	7.39	62.41
25	Childress	10	60.9	0.16	97.67
9	Waco	124	40.2	3.08	78.22
13	Yoakum	12	29.5	0.41	90.00
19	Atlanta	6	25.2	0.24	92.59
10	Tyler	2	22.6	0.09	95.83
17	Bryan	229	19.2	11.93	39.53
22	Laredo	0	9.2	0.00	100.00
8	Abilene	0	8.5	0.00	100.00
11	Lufkin	0	2.5	0.00	100.00
6	Odessa	0	1.7	0.00	100.00
21	Pharr	0	1.6	0.00	100.00

User Costs

The inputs used for this parameter were described in Chapter 4 of this report. After running sensitivity analyses on the parameters that influence the user costs in the RealCost software, the research team ranked the inputs in order of importance, based on how much they influenced the total user cost. The parameters are listed below in order of decreasing importance (i.e., the first parameter is the most important). A suggested value is also discussed for each parameter.

- Work zone time

  After running a sensitivity analysis, the research team suggests that the maintenance work be done at night, preferably between the hours of 9 pm and 6 am.
- Number of lanes opened during construction / work zone capacity (vehicle per hour per lane)

As discussed in Chapter 4, these two parameters are directly related. It is obvious that the more lanes opened to traffic, the higher the vehicle capacity, the lower user costs will be. However, the time of day at which the work is done will greatly influence this parameter.

The research team suggests that when working at night, on a three-lane facility, it is best to have one lane open to traffic and two lanes closed for work. If the work is done during the day, it is best to have two lanes opened to traffic.

- Maximum queue length

  If the job is done at night, the queue length is not a parameter to consider. However, if the work is done during the day (i.e., 8 am to 5 pm), the research team suggests that the maximum queue length be minimized (i.e., 5 miles).

- Queue dissipation capacity

  This parameter did not greatly influence the user costs, therefore the research team recommends that it be minimized whenever possible (i.e., 1500 vphpl).

- Work zone length

  The two lengths analyzed for this parameter did not influence the user costs very much.

- Work zone speed limit

  The research team recommends a work zone speed limit of 55 mph just to lower the user costs.

- Work zone duration (days)

  It is obvious that the longer the duration, the higher the user costs. Since this parameter depends on how many crews are working, the research team recommends that it be minimized whenever possible.

Salvage Value

If the designer decides to generate salvage values, the designer will first need to determine if the pavement will need to be removed at the end of the 30-year analysis period. If this is the case, the designer should use the salvage value recommendations in the FPS-19W design program for the flexible pavement design, and determine the value of the concrete pavement design by dividing the cost of removal by the cost of new material it could replace in a new pavement structure. For example, the cost of concrete pavement removal according to TxDOT Item 104-2001, Removing Concrete Paving, is approximately $6.00 per square yard based on a 12-month moving average from October 2007 to October 2008. The salvaged concrete material can be used for a 6-inch thick cement stabilized flexible base that could be used in a new pavement structure. The 12-month moving average for TxDOT Item 249, Flexible Base, indicates that the flexible base would cost $5.17 per square yard. The resulting difference between the cost of removal and the cost of the flexible base would be -$0.83 per square yard (i.e., a negative value). This would result in a negative salvage value.

However, if the designer determines that the pavement structure can remain in place and be used for an overlay, the salvage value can be simply based on the cost of the overlay versus cost of a new pavement. So, in other words, the salvage value would be:

Salvage Value,% =[1 – (Cost of the future overlay/Cost of new pavement structure)]*100

This should be relatively simple to calculate since the designer already has to generate the cost of a new pavement structure for the design.

CHAPTER 6:
FINDINGS AND RECOMMENDATIONS

The main goal of this research was to provide TxDOT with guidelines, including a practical protocol for deciding whether or not to develop pavement structure alternatives for alternate bids. By using the guidelines for alternate bids, TxDOT should get the best value for a project. Alternate bids should attract more contractors, increasing competitiveness among them with the aim of resulting in lower construction costs.

The guidelines are supported by a user friendly tool developed under this research. The Alternate Pavement Design Analysis Tool will assist in determining if pavement alternates should be considered. The FHWA RealCost software can also be used for further life-cycle cost analysis when including user costs.

A modification to the TxDOT Design Summary Report (DSR) (*45*) is proposed for implementing the guidelines developed in this research.

WHEN SHOULD THE DEPARTMENT CONSIDER ALTERNATE PAVEMENT DESIGNS?

It was found in this research that the following characteristics can make a pavement unsuitable for offering alternative pavement designs in the plans. The researchers recommend that these characteristics be incorporated into the DSR:

- This is a pavement widening project.
- The project does not involve new construction or reconstruction.
- The pavement is less than 500 feet in length.
- The pavement is less than 5 miles in length, and both connecting pavements are either rigid or flexible pavements.
- There are areas of the pavement where truck traffic will be stationary for long periods of time.

In addition, the researchers generated two options that can be incorporated in the DSR revision. The first option states that pavement alternates should not be used if the project's one-way truck traffic ADT value range is below 300 or above 2,000. The second option states that pavement alternates should not be used if the concrete pavement thickness for the project generated from the 1993 AASHTO Guide (*31*) design procedure is less than 8 inches or 12 inches and greater. This is a preliminary evaluation prior to the design. If this pavement does not include any of the above characteristics, it is recommended to use APDAT to further explore offering alternative pavement designs.

The APDAT decision analysis tool incorporates lower and upper limit ESALs for each district that are based on concrete pavement thicknesses of 8 inches and 12 inches using the appropriate inputs in the 1993 AASHTO rigid pavement design procedure. If the ESALs are outside the districts' limits, the APDAT tool indicates that pavement alternates should not be considered.

If after conducting the preliminary evaluation the pavement appears to be a candidate for alternative pavement design, then alternate designs should be generated. After developing the Flexible and Rigid Pavement Designs, a life-cycle cost analysis of both alternatives is conducted. If the LCCA difference between the alternatives is more than 20 percent, the researchers recommend that the engineer should select the alternative with the lowest life-cycle cost. If the LCCA difference between the alternatives is less than 20 percent, then alternate pavement design is recommended for the bidding process.

RECOMMENDATIONS FOR DEVELOPING ALTERNATE PAVEMENT DESIGNS

The TxDOT Pavement Design methods (*29*), Flexible Pavement System (FPS-19W) and the 1993 AASHTO Guide (*31*) rigid pavement design procedure should be used for the development of alternative pavement designs. General guidelines currently used by TxDOT concerning the design of pavement alternates for new construction and reconstruction projects are:

- Use 30 years as the design life.
- Use 4.5 and 2.5 for the initial and terminal serviceability values.
- Use 95 percent reliability.
- Use a time to first overlay of 15 years for the flexible pavement design.
- Design the overall subgrade and pavement structure to have a Potential Vertical Rise no greater than 1.0 inch as calculated by Tex-124-E from soil tests in a soil column

15 feet deep as measured from the proposed finished pavement grade. Alternatively, provide material with an effective Plasticity Index of less than 25, to a depth of 8 feet from finished pavement surface.

The use of life-cycle cost analysis is recommended. An interest rate based on current financial data should be used. For initial construction costs, the designers should use thicknesses generated for flexible and rigid pavement designs using the recommended design input values developed by TxDOT. For routine maintenance costs, the researchers recommend consulting with appropriate district personnel as to appropriate costs. The researchers analyzed the maintenance costs contained in the Fiscal Year 2008 PMIS database and included it in a separate worksheet; this information can be used as a basis of discussion with district personnel.

For timing and costs related to future asphalt concrete pavement overlays, seal coats, or other surfacings, as well as future patching for rigid pavements, the researchers recommend consulting with appropriate district personnel. In addition, the researchers recommend using information from well-performing projects in their respective areas that are at least 20 years old.

If the designer decides to generate salvage values, the designer will first need to determine if the pavement will need to be removed at the end of the 30-year analysis period. If the pavement structure would be removed, the designer should use the salvage value recommendations in the FPS-19W design program for the flexible pavement design; and determine the value of the concrete pavement design by determining the cost of removal and the cost of new material it could replace in a new pavement structure. If the pavement structure will not be removed, then the salvage value can be simply a function of the cost of a future overlay versus the cost of a new pavement structure. User costs could be considered in the analysis but only if deeper analysis is desired.

IMPLEMENTATION

In order to effectively implement the recommendations documented by this research project, the researchers suggest that TxDOT conduct pavement alternate training courses for design personnel. These courses should involve the following:

a. discussing the TxDOT guidelines for pavement alternates,
b. using the TxDOT PMIS mainframe system or MapZapper to generate the PMIS Multi-Year Ratings and Scores Report for well-performing pavement sections (this

report can be used to help determine appropriate maintenance costs and rehabilitation timing for LCCA),

c. using the TxDOT intranet web site to access pavement photos taken by TxDOT pavement data collection equipment since 2003 (these photos can be used to possibly determine if the PMIS data accurately reflect pavement conditions and to possibly help determine rehabilitation timing for LCCA),
d. using the Texas Successful Flexible Pavements Database (this database can be possibly used for determining appropriate rehabilitation timing for flexible pavement LCCA), and
e. using the APDAT spreadsheet, the Maintenance Cost spreadsheet, and the FHWA RealCost software.

In addition, the researchers also suggest that TxDOT maintain a database of projects that used pavement alternates. TxDOT personnel can use the information in this database to determine if adjustments are needed to the department's pavement alternates guidelines. The researchers do expect that adjustments would be needed as TxDOT personnel gain experience in developing pavement alternates. This database should include the typical sections and estimates used in the set of plans, the pavement design inputs used for developing the alternates, life-cycle cost analyses, and the contractor's project agreement estimate.

REFERENCES

1. Kadiyali, L.R., and Danavate, M.G. *A Comparative Study of the Economics of Rigid and Flexible Pavements.* The Indian Concrete Journal, India, 1984.

2. Mitchell, M., and Walker, R. *The Economic of Pavement Type Selection.* Department of Transportation, Pretoria, South Africa, 1985.

3. HDM 4 Version 2, http://www.hdmglobal.com/hdm4version2.asp. Accessed on January 30, 2008.

4. Pittman, D.W., and Opelika, A. *Development of a Reliability-Based Design Procedure for Rigid and Flexible Airfield Pavement.* U.S. Army Corps of Engineers, Washington D.C., 1996.

5. *Pavement Type Selection Processes*. Asphalt Pavement Alliance, Lexington, Kentucky, 2004.

6. Newcomb, D. *Decisions, Decisions: The Pavement Type Selection Process Can Help you Make Them*. Asphalt Pavement Association of Oregon, Portland, Oregon, 2004.

7. Villacres, J.N. *Pavement Life-Cycle Cost Studies Using Actual Cost Data.* Asphalt Pavement Alliance, Lexington, Kentucky, 2005.

8. Von Quintus, H.L., Mallela, J., and Jiang, J. *Expected Service Life and Performance Characteristics of HMA Pavement in LTPP.* Asphalt Pavement Alliance, Texas, 2005.

9. Asphalt Institute, http://www.asphaltinstitute.org/store_product.asp?inve_id=238 . Accessed on January 30, 2008.

10. American Pavement Concrete Association (APCA), http://www.pavement.com/Concrete_Pavement/About_Concrete/Why_Concrete_Pavement/index.asp. Accessed on January 30, 2008.

11. *Life-Cycle Cost Analysis: A Guide for Comparing Alternate Pavement Designs.* American Concrete Pavement Association, Illinois, 2002.

12. American Concrete Pavement Association, http://www.pavement.com/CPP/2007/CPP-9-07.html. Accessed on January 30, 2008.

13. Buncher, M., Blow, M., and Walker, D. *ACPA's StreetPave: User Beware*. http://www.asphaltmagazine.com/singlenews.asp?comm=0&list_code_int=MAG01-INT&item_ID=1392. Accessed on January 30, 2008.

14. Walls, J. and Smith, M.R. *Life-Cycle Cost Analysis in Pavement Design – In Search of Better Investment Decisions.* Publication No. FHWA-SA-98-079, U.S. Department of Transportation, Washington D.C., 1998.

15. *Life–Cycle Cost Analysis Primer*. U.S. Department of Transportation and Federal Highway Administration, Washington D.C., 2002.

16. Maher, M., Marshall, C., Harrison, F., and Baumgaertner, K. *Context Sensitive Roadway Surfacing Selection Guide.* Golder Associates, Inc., for the National Highway Association, Lakewood, Colorado, 2005.

17. *Highway Economic Requirements System-State Version 2.0 (HERS-ST).* Overview. U.S. Department of Transportation and Federal Highway Administration, Washington D.C., 2002.

18. Stephanos, P.J. *Memorandum – Clarification of FHWA Policy for Bidding Alternate Pavement Type of the National Highway System*. U.S. Department of Transportation and Federal Highway Administration, November 2008.

19. Velado, M. *Life-Cycle Cost Analysis Procedures Manual*. California Department of Transportation (Caltrans), Sacramento, California, 2007.

20. Demos, G.P. *Life-Cycle Cost Analysis and Discount on Pavements for the Colorado Department of Transportation.* Report No. CDOT-2006-17, Colorado Department of Transportation (CDOT), Denver, Colorado, 2006.

21. Kentucky Transportation Cabinet. *Pavement Type Selection Policy.* http://transportation.ky.gov/design/pavedesign/docs/Appendix%20E.pdf. Accessed January 26, 2009.

22. Temple, W.H., Zhang, Z., Lampert, J., and Zeringue K.M. *Agency Process for Alternate Design and Alternate Bid of Pavements.* Louisiana Department of Transportation and Development (LADOTD), Baton Rouge, Louisiana, 1998.

23. *Pavement Design and Type Selection Process.* Missouri Department of Transportation (MoDOT), Jefferson City, Missouri, 2004.

24. Engineering Policy Guide Homepage. Missouri Department of Transportation. http://epg.modot.mo.gov/index.php?title=Alternate_Pavement. Accessed January 26, 2008.

25. Smith, K.L., Stanley, M., Vandenbossche, J., and Morian, D. *Pavement Life-Cycle Cost Analysis*. Pennsylvania Department of Transportation (PennDOT), Harrisburg, Pennsylvania, 2005.

26. *Pavement Type Selection Process – Memorandum.* South Carolina Department of Transportation (SCDOT), Columbia, South Carolina, 2007.

27. Rangaraju, P.R., Amirkhanian, S., and Guven Z. *Life-Cycle Cost Analysis for Pavement Type Selection*. Clemson University and South Carolina Department of Transportation. Clemson, South Carolina, 2008.

28. MacDonald, D. *Pavement Type Selection Protocol*. Washington State Department of Transportation (WSDOT), Olympia, Washington, 2005.

29. *Pavement Design Guide Revised October 2006*. Texas Department of Transportation, Austin, Texas, 2006.

30. Scullion, T., and Liu, W. *Flexible Pavement Design System (FPS) 19W: User's Manual*. Research Report No. TX-02/1869-1, College Station, Texas, 2001.

31. *AASHTO Guide for Design of Pavement Structures*. American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 1993.

32. *DARWIN, Pavement Design, Analysis and Rehabilitation for Windows*. http://www.aashtoware.org/?siteid=28&pageid=76. Accessed on August 5, 2007.

33. ARA, Inc., ERES Consultants. *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, Part 1: Introduction.* National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Champaign, Illinois, 2004.

34. *Basic Skills for Using PMIS on the TxDOT Mainframe Computer.* Texas Department of Transportation, Austin, Texas, 2002.

35. *TxDOT Maintenance Management Information System (MMIS) Data Dictionary*. Texas Department of Transportation, Austin, Texas, 2002.

36. *AASHTO Site Manager*, http://aashtoware.org/?siteid=28&pageid=103. Accessed on March 1, 2005.

37. *DCIS User Manual (Revised October 2004).* Texas Department of Transportation, Austin, Texas, 2004.

38. Krugler, P.E., Chang-Albitres, C.M., Scullion, T., Chowdhury, A., Maldonado-Melendez, A., and Lin, Y.*A Database for Successful Pavement Sections in Texas – Including Both Experimental and Non-Experimental Pavements*. Research Report 5472-S, Texas Transportation Institute, College Station, Texas, 2008.

39. Beg, M., Zhang, Z., and Hudson R. *A Rational Pavement Type Selection Procedure.* Publication FHWA TX 04 0-1734-S, Texas Department of Transportation, Austin, Texas, 1998.

40. R. Haas, Hudson, W.R., and Zaniewski, J. *Modern Pavement Management*, Krieger Publishing Company, Malabar, Florida, 1994.

41. Peterson, D.E. *Life-Cycle Cost Analysis of Pavements*, NCHRP Synthesis 122, TRB, Washington, D.C., 1985.

42. Epps, J.A., and Wootan, C.V.. *Economic Analysis of Airport Pavement Rehabilitation Alternatives An Engineering Manual*, Report DOTFAA - RD-81-78, FAA, DOT, Washington, D.C., 1981.

43. Life-Cycle Cost Analysis. *Real Cost v. 2.1 User Manual,* FHWA. May 2004.

44. Bohuslav, T. *Value of Time and Road User Costs.* Texas Department of Transportation, Austin, Texas, April 25, 2005.

45. Design Report Summary, Project Development Process Manual, Texas Department of Transportation, Austin, Texas, 2004. http://www.txdot.gov/txdot_library/forms/business/contractors_consultants/design.htm. Accessed on August 5, 2007.

APPENDIX A:
RESULTS FROM FPS-19W AND TSLAB RUNS FOR DIFFERENT LAYER STRUCTURES
(SEE COMPACT DISK ATTACHED TO BACK COVER)

APPENDIX B:
ALTERNATE PAVEMENT DESIGN ANALYSIS TOOL (APDAT) QUICK START GUIDE
(SEE COMPACT DISK ATTACHED TO BACK COVER)