OKLAHOMA TRANSPORTATION CENTER

ECONOMIC ENHANCEMENT THROUGH INFRASTRUCTURE STEWARDSHIP

ALTERNATE BIDDING STRATEGIES FOR ASPHALT AND CONCRETE PAVEMENT PROJECTS UTILIZING LIFE CYCLE COST ANALYSIS (LCCA)

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16. ABSTRACT

Recent changes in pavement materials costs have impacted the competitive environment relative to the determination of the most cost effective pavement structure for a specific highway project. In response, State highway agencies have renewed their interest in using alternate pavement type bidding procedures to determine the appropriate pavement type. This research project developed an alternative bidding procedure for pavement projects. Not all highway projects are candidates for alternate bidding. A step by step procedure can help identify candidate highway projects for alternate bidding. In addition to developing a deterministic life cycle cost (LCC) analysis model using I40 interstate pavement data, the research team also developed a novel approach, namely, realistic LCCA model. This approach uses the association rule mining technique to find and probabilistically organize various treatment patterns applied to pavements in the past. A case study conducted in this project revealed that this realistic LCCA model is more reliable and is expected to provide better predictions on LCC. Moreover, since this approach is based upon the historical performance of pavements, it is expected to be easier to draw consensus between the asphalt and concrete industries in calculating life cycle costs. A spread sheet based program is developed for ODOT to calculate LCC for flexible and rigid pavement alternatives. This program enables ODOT to enter project information such as project scope, analysis period, estimated unit prices, miscellaneous items, mobilization, and construction added costs for asphalt and concrete pavement projects and obtain deterministic and realistic LCCs of both pavement types as well as LCC factor which should be used during the alternate bidding process.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.40	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm
ft^2	square feet	0.0929	square meters	m^2
yd^2	square yards	0.8361	square meters	m^2
ac	acres	0.4047	hectares	ha
mi^2	square miles	2.590	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0283	cubic meters	m^3
yd^3	cubic yards	0.7645	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.448	Newtons	N
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yd
km	kilometers	0.6214	miles	mi
		AREA		
mm^2	square millimeters	0.00155	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.471	acres	ac
km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME		
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallons	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	Newtons	0.2248	poundforce	lbf
kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

Alternate Bidding Strategies for Asphalt and Concrete Pavement Projects Utilizing Life Cycle Cost Analysis (LCCA)

Final Report

July 2012

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1 INTRODUCTION

1.1 Overview

Recent changes in pavement materials costs have impacted the competitive environment relative to the determination of the most cost effective pavement structure for a specific project. In response, State Highway Agencies (SHAs) have renewed their interest in using alternate pavement type bidding procedures to determine the appropriate pavement type. Also, there has been a growing consensus that a combination of sound design procedures along with improved materials and construction procedures can result in both rigid and flexible pavements that are viable choices for a wide spectrum of terrain and traffic conditions [1].

Even though a large number of DOTs are aware of the benefits of life cycle cost analysis (LCCA) and have used it for assessing long-term economic performance of their highway projects, there are only a small number of DOTs that have developed and implemented alternate bidding procedures for pavement type selection. These states include Missouri and Louisiana. The Louisiana Department of Transportation and Development (LADOTD) specifically reports that their Alternate Design and Alternate Bid (ADAB) procedure has shown a trend toward reduced bid prices that may be related to increased competition [1]. Missouri DOT (MoDOT) [2] also reports that their first alternate bidding experiment on two projects yielded significant savings, approximately $770,000 in total from the engineer's estimate on the original design. The Oklahoma Department of Transportation (ODOT) is one of the DOTs that is not utilizing LCCA for their highway projects and does not have alternate bidding procedures for pavement type selection. However, Oklahoma is one of the states that use both rigid and flexible pavements more frequently as compared to the average state in the U.S., which provides a healthy and promising environment to implementing this long-term cost saving approach.

The ultimate goal of this study is to develop alternate bidding procedures for pavement type selection utilizing LCCA. This new procedure will promote a more cost effective use of highway construction funds through enhanced fair competition among pavement industries. One of the key technical issues in developing an alternate bidding procedure is to have non-disputable guidelines from both the asphalt and concrete paving industries for determining timing of maintenance and rehabilitation (M&R) activities over the analysis period. This study uses a powerful data mining process to quantitatively determine the patterns of M&R activities of Oklahoma highways, as well as the timing of the activities and their associated costs using ODOT's Pavement Management System (PMS) data and historical highway project data on M&R activities. This study develops reliable LCCA models for different pavement types based on Federal Highway Administration (FHWA) recommendations and also investigates critical factors and conditions that should be considered when alternate bidding is permitted. Another key issue to the success to this specific project is to reach a consensus on the outputs of each stage of the project among stakeholders, especially the two paving industries. This project uses a Study Advisory Group (SAG) that consists of experts and stakeholders throughout the course of the project. The use of the SAG helps identify issues to be resolved in a timely manner.

The procedure that is developed in this study can be used as a decision aid tool to select a pavement project that offers a higher return to ODOT over the lifecycle of the pavement instead of only low initial construction costs. For projects where alternate bids are not allowed, design engineers can still use this procedure to determine the most economical design. Pavement contractors may use this procedure to determine their competitiveness on their alternate bid. It is anticipated that the implementation of the alternate bidding procedure will increase the bid pool, which has proven to result in lower bid prices.

1.2 Background

When alternate bids are permitted, the state agency must have a well-developed procedure for a fair and reasonable comparison of pavement types and a process that both pavement industries can agree on and endorse. The FHWA has recommended that the following factors should be considered prior to making the decision to utilize alternate bidding procedures [3].

a) Comparable (or equivalent) design: alternate design that performs equally, provides the same level of service, and has similar life-cycle costs.
b) Realistic discount rate: future agency costs should be discounted to Net Present Value (NPV) of the project or equivalent uniform annual costs using the appropriate (real) discount rate

c) Consideration of uncertainty: the impact of uncertainty in factors such as performance life, material costs, construction duration, and future actions should be considered in the determination of total lifecycle cost
d) Realistic rehabilitation strategy: the rehabilitation strategy should accurately reflect current or anticipated owner-agency pavement management practices
e) Subjective considerations: an owner-agency may consider non-cost related factors such as constructability, type of adjacent pavements, recycling, and conservation of materials, and
f) Appropriate application: alternate pavement type bidding procedures should only be used where the pavement items impacted by the alternate bid are likely to influence the final determination of the lowest responsive bidder for the project.

The economic assessment of a pavement project over its entire life is an effective approach not only to find the lowest cost option by evaluating all the expected costs incurred during the service life but also to document and predict the effects of an agency's expected future activities for the project. FHWA and other federal agencies such as the American Association of State Highway and Transportation Officials (AASHTO) have promoted the use of lifecycle based economic evaluation for transportation investment decisions, including pavement projects, since the Intermodal Surface Transportation Equity Act of 1991. The national Highway System Designation Act of 1995 further imposed a new requirement making LCCA compulsory for National Highway System (NHS) projects costing more than $25 million. The requirement was annulled under the Transportation Equity Act for the 21st Century (TEA-21) in 1998, but FHWA and AASHTO remain active in assisting the states in developing their own LCCA procedures. FHWA is required by TEA-21 to fund research that "expands the knowledge of implementing LCCA" (23 USC 502). Lifecycle costs must still be considered as part of the FHWA's value engineering process for NHW projects costing more than $25 million (23 CFR Part 627) [4]. On November 13, 2008 FHWA sent a memorandum to each SHA to provide a guideline for alternate bidding using LCCA [3].

The current practice in ODOT for pavement projects starts with the development of different pavement designs by the roadway design division. The parameters that are considered in this design stage include initial average daily traffic, percent heavy trucks, anticipated traffic growth, in-situ soil characteristics, desired performance period, and paving material characteristics. The design details and plans with estimated initial construction costs are sent to the division where the project will actually take place. The division engineers review the appropriateness of the different designs by investigating site conditions, environmental concerns, expected construction costs, etc. and finally recommend one of the designs for bid letting. This current procedure does not provide a means to meet and evaluate long-term performance requirements for a project. It does not allow the division engineers to make fully informed decisions on choosing a best project option because of the failure of providing comprehensive costs associated with each design over the entire life of the project. The current procedure also eliminates an opportunity for the paving industries to come up with an alternate design that may promise better long-term economic benefits over the selected design.

1.3 Objectives

The ultimate goal of this study is to develop alternate bidding procedures for pavement type selection utilizing LCCA. This new procedure promotes a more cost effective use of highway construction funds through enhanced fair competition among pavement industries. In order to achieve the overall goal, the following objectives mush be accomplished.

a) Develop a decision aid framework to determine whether a project is suitable for alternate pavement type bidding.
b) Identify timing of maintenance and rehabilitation activities and their associated costs.
c) Identify sequence of maintenance and rehabilitation activities and their associated costs.
d) Develop deterministic and realistic lifecycle cost models for flexible and rigid pavement designs.
e) Develop alternate bidding procedures for pavement type selection

1.4 Research Plan

The overall research plan includes eight major work tasks as illustrated in Figure 1.1. The following sections describe each work task as specifically as possible.

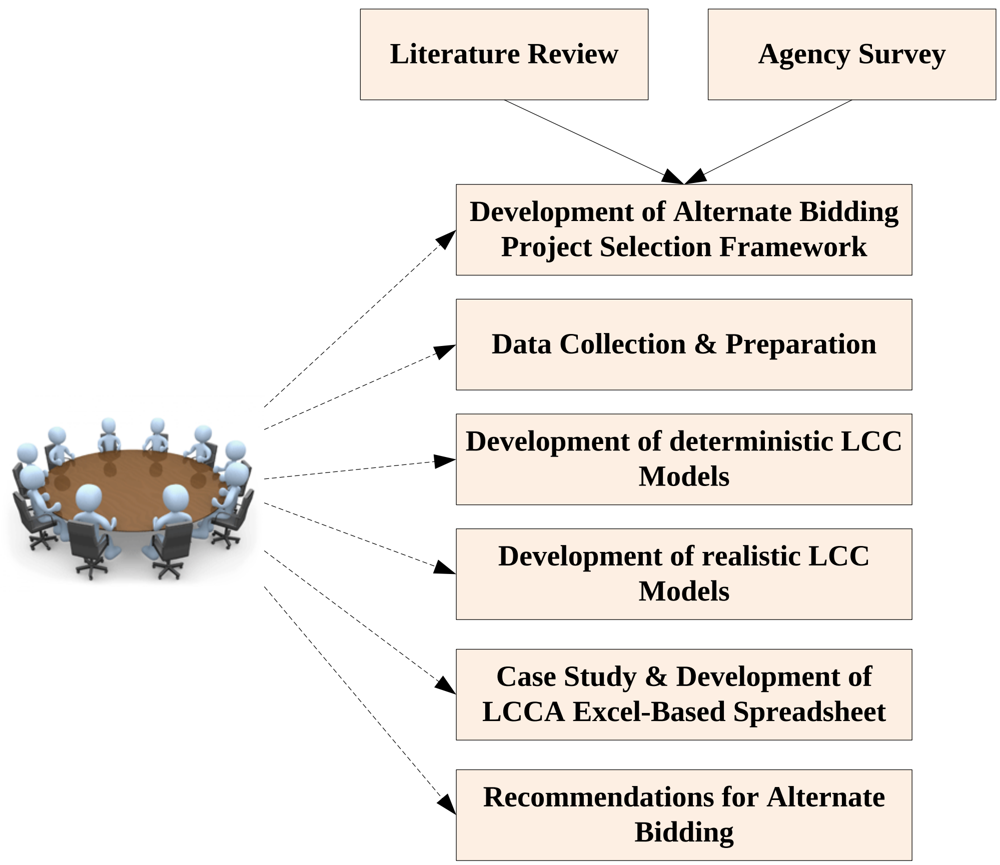

Figure 1.1 Research Tasks Framework

1.4.1 Formation of a Study Advisory Group (SAG)

A Study Advisory Group (SAG) was formed and a kick-off meeting was held in the very early stage of this project. One of the key issues to the success of this project was to reach consensus on the outputs of each stage of the research study among stakeholders, especially the two paving industries. Missouri DOT [2] reports that disagreement over design-life assumptions by the paving industries was one major negative aspect of alternate bidding. The research progress and the findings from each stage were updated by holding regular meetings with the SAG members. It also helped the research team to identify issues to be resolved during the course of research. The SAG members were as follows, Jeff Dean (Pavement Design, ODOT), George Raymond (State Construction Engineer, ODOT), William Dickinson (Pavement Management, ODOT), Brian Schmitt (ODOT Office Engineer), Alex Calvillo (ODOT Assistant State Maintenance Manager), Waseem Fazal (Pavement and Materials Engineer, FHWA-Oklahoma Division), Brent Burwell (Executive Director, Oklahoma/Arkansas Chapter of American Concrete

Pavement Association), Connie Rozean-Pruitt (Former Executive Director, Oklahoma Asphalt Pavement Association), Larry Patrick (Executive Director, Oklahoma Asphalt Pavement Association), Craig Parker (Silver Star Construction Co).

1.4.2 Literature Review

There are rich domestic and international publications in the areas of pavement management systems, deterioration models of pavements, life cycle assessment of pavements, cost analysis of maintenance and rehabilitation options for pavements, infrastructure maintenance budgeting, etc. These documents together with experiences of other SHAs in alternate pavement type bidding strategies and LCCA are discussed in the second chapter.

1.4.3 Agency Survey

This stage includes interviews with ODOT engineers including roadway design engineers, pavement management engineers, and division engineers to document the current procedures in pavement type selection and determining M&R activities for different pavement families. A questionnaire survey was also performed in this stage to identify the significant subjective considerations in pavement type selection. Chapter three contains a summary of the information obtained during the interviews with ODOT engineers and the results of the questionnaire survey.

1.4.4 Development of Alternate Bidding Project Selection Framework

According to FHWA's recommendations, the appropriate application of alternate bidding requires a list of factors that need to be checked prior to selecting a project for this type of bidding. In some projects, one pavement type is clearly superior based on subjective considerations. Therefore, projects ought to be checked against a set of criteria such as subjective and engineering considerations to determine whether a certain pavement type or an alternative has preference over other options. An alternate bidding project selection framework is developed for ODOT in Chapter three. This framework is based on the results of the questionnaire survey and pavement type selection criteria that are considered significant by the stakeholders. If there is no preference for any of the alternatives, the project is appropriate for alternate pavement type bidding.

1.4.5 Data Collection & Preparation

Highway maintenance and rehabilitation records are collected from ODOT Pavement Management Branch. The interstate structural history data set for Interstate 40 (in Oklahoma) was utilized for the purpose of association analysis. This data set is a record of the construction and major treatment projects on the Interstate 40 in Oklahoma. This report has been issued on a yearly basis since 1994. In this study, the 2010 data set is used. The primary sources of project information include Planning & Research Division long cards, Bureau of Public Roads interstate strip maps, as-built drawings, and ODOT Oracle database. A five step approach for data preparation used in this study is introduced and discussed in Chapter four.

1.4.6 Development of Deterministic LCC Models

This stage requires a data intensive analysis. The Interstate Highway Structural Pavement History is used to predict performance of different pavement types over time. All sections of road in the state highway systems are categorized into pavement families based on pavement type, traffic volume, and presence of “D” cracking (for JCP only). Sections within a pavement family are expected to perform similarly and thus share a common performance or deterioration curve. The pavement families used in ODOT’s PMS are shown in Table 1.1. The inability to gain consensus on M&R activity intervals from all stakeholders was the main reason why alternate bids on pavement were not used for several years in Missouri [2]. In chapter five, the timing and sequence of M&R activities are studied and two deterministic LCC models are developed for Asphalt Pavements (AC) and Jointed Plain Concrete Pavement (JPCP) with very high volume.

1.4.7 Development of Realistic LCC Models

In this stage a powerful data mining process will be applied to develop right timing and sequence of M&R activities for AC and DJCP with very high level of traffic. Data mining has mostly been used by statisticians, data analysts, and the management information system (MIS) communities. Even though this new data analysis process has not been actively employed in the engineering disciplines, the concept of finding hidden patterns from data is not new because many statistical analysis tools have been actively used to solve problems in the engineering domain. Data mining starts with available data first and then uses the data to solve a problem by selecting and using the most appropriate statistical or artificial intelligence-based prediction models. The data mining technique used in this study is called association rules mining. This technique is utilized to identify the significant sequential patterns in the historical pavement M&R activities. The results of this analysis help to identify the significant pavement treatment strategies for each pavement family as well as the probability associated with each strategy. Chapter six discusses association rules mining and how the results of this analysis are utilized to develop realistic LCC models for different pavement families.

Table 1.1 Classification of Pavement Types

Asphalt Pavements (AC)	Concrete Pavements	Composite pavements
a) AC Low Volume – AC with less than 2,000 AADT b) AC Moderate Volume – AC with 2,000 – 10,000 AADT c) AC High Volume – AC with 10,000 – 40,000 AADT d) AC Very High Volume – AC with over 40,000 AADT	e) CRCP Low volume – CRCP with less than 10,000 AADT f) CRCP High volume – CRCP with over 10,000 AADT g) DJCP – Dowel Jointed Concrete Pavement h) DMJCP – Mesh Dowel Jointed Concrete Pavement i) Jointed Plain Concrete Pavement (JPCP) Low Volume – JPCP with less than 10,000 AADT j) JPCP High Volume – with over 10,000 AADT k) JPCP "D" – D cracked JPCP	l) Composite Low Volume – AC over PC with less than 10,000 AADT m) Composite Moderate Volume – with 2,000-10,000 AADT n) Composite High Volume – with 10,000 AADT

1.4.8 Case Study & Development of LCCA Excel-Based Spreadsheet

A project in Interstate 40 is selected to evaluate the performance of the alternate pavement type bidding project selection framework, deterministic LCC models, and realistic LCC models. During the case study, an Excel-based spreadsheet is also developed to assist ODOT in the process of performing LCCA. The LCC adjustment factor for this project is calculated based on both deterministic and realistic LCC models and the results are compared together. The research team believes that realistic LCCA would provide ODOT with a LCC factor which is closer to actual costs. The realistic LCCA captures the effects of uncertainty in estimates of timing or treatment activities for each pavement family. The process and results of the analysis are discussed in Chapter seven.

1.4.9 Recommendations for Alternate Bidding

The findings and the models developed in the previous tasks are organized and summarized into a procedural format. A set of recommendations are also made for ODOT in order to help them start applying alternate pavement type bidding to its projects. FHWA Special Experimental Program Number 14 (SEP-14) provides SHAs with the opportunity to utilize and evaluate alternate bidding. The experiences of other states in alternate bidding as well as the recommendations for ODOT are discussed in Chapter eight.

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Chapter 2 OVERVIEW OF ALTERNATE BIDING PROCESSES

2.1 Introduction

When more than one alternate are deemed to be equal over the design life and there is a reasonable possibility that the least costly design approach will depend on competitive circumstances, alternate bidding procedures can be used. Through the past decades, transportation departments have made numerous decisions about the type of pavements for the road construction, reconstruction or rehabilitation activities. Although the decision used to be only based on the availability of materials, equipment, volume of traffic, type of road and initial cost of the pavement, some of the transportation departments have started considering LCCA by taking user cost, maintenance cost, time to first rehabilitation, salvage value and design life into account [5]. Since there is no such thing as truly equivalent pavement designs, the FHWA has allowed states to make some bid adjustments to account for differences in life-cycle costs under FHWA SEP-14 as an “Innovative Contracting.” Several state DOTs have performed projects utilizing this contracting method and tried to develop a fair environment where asphalt and concrete industries can compete efficiently. This bidding method can be categorized under multi-parameter bidding strategies. A generic name for this type of bidding can be A+L bidding, where A stands for the traditional bid and L stands for the life-cycle cost of the pavement design that has been selected by the contractor. The challenge in A+L bidding is developing a framework for LCCA that both industries agree upon. The contractor with the lowest Total combined cost (TCB) would win the bid contract.

$$TCB = A + L \qquad \text{Equation 2.1}$$

where; TCB = total combined cost,

A = base bid,

L = life-cycle cost

The economic assessment of a pavement project over its entire life is an effective approach not only to find the lowest cost option by evaluating all the expected costs incurred during the service life but also to document and predict the effects of an agency’s expected future activities for the project. FHWA and other federal agencies such as the American Association of State Highway and Transportation Officials (AASHTO) have promoted the use of life-cycle based economic evaluation for transportation investment decisions, including pavement projects, since the Intermodal Surface Transportation Equity Act of 1991. The National Highway System Designation Act of 1995 further imposed a new requirement making LCCA compulsory for National Highway System (NHS) projects costing more than $25 million. The requirement was annulled under the Transportation Equity Act for the 21st Century (TEA-21) in 1998, but FHWA and AASHTO remain active in assisting the states in developing their own LCCA procedures. FHWA is required by TEA-21 to fund research that "expands the knowledge of implementing LCCA" (23 USC 502). Life-cycle costs must still be considered as part of the FHWA's value engineering process for NHS projects costing more than $25 million (23 CFR Part 627) [4]. Recently, FHWA sent a memorandum to each SHA to provide a guideline for alternate bidding using LCCA [3]. Table 2.1 lists all the historical regulations/policies regarding LCCA and alternate bid in United States.

Table 2.1 Regulations and Policies Regarding LCCA and Alternate Bid

Year	**Regulation / Policy**	**Message**
1960	An Informational Guide on Project Procedures, produced by AASHO.	Importance of competition between pavement industries.
1981	Pavement Type Selection Policy Statement, FHWA.	Necessity of economic analysis based on LCC of pavements. Where applicable, the use of alternate bids may be permitted.
1990	Intermodal Surface Transportation Equity Act, expired in 1997.	Promoting use of LCC based economic evaluation.
1995	National Highway System Designation Act.	Mandating LCCA for NHS projects costing more than $25 million.
1996	Pavement (Design) Policy, FHWA	No bearing on pavement type selection.
1998	Transportation Equity Act for the 21st Century (TEA-21)	Compulsory LCCA was annulled. Fund research that "expands the knowledge of implementing LCCA".
1999	23 CFR Part 626	Discourage use of alternate bids, difficult in developing truly equivalent pavement designs.
2001	23 CFR Part 627	LCCA must be considered as part of VE process for NHS projects costing more than $25 million.
2008	Clarification of FHWA Policy for Bidding Alternate Pavement Type on the National Highway System	Factors that should be considered prior to utilizing alternate bidding procedures.

2.2 FHWA Recommendations

Changes in pavement materials cost is one of the most important factors that have triggered State Highway Agencies (SHA's) to show interest in using alternate pavement type bidding procedures to determine the appropriate pavement. Hence, FHWA issued a memorandum with clarifications of 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 [3]. The memorandum indicates several factors that should be considered prior to determining that alternate bidding procedures should be used. These factors include:

- Designs must be equivalent
- Realistic discount rate
- Consideration of uncertainty
- Realistic rehabilitation strategy
- Subjective considerations: considering non-cost related factors such as constructability, type of adjacent pavements, recycling, and conservation of materials.
- Appropriate application: alternate pavement type bidding procedures should only be used where pavement items impacted by the alternate bid are likely to influence the final determination of the lowest responsive bidder for the project. Projects with substantial bridge or earthwork items are generally not suited for alternate bids [3].

2.3 Experience of Highway Agencies

Louisiana Department of Transportation and Development (LADOTD) has developed a model called alternate design, alternate bid (ADAB) that allows selection of pavement type through the bid processes. The model is known as A+B+C, where A is contractor's base bid, B is time-based bidding that may also include incentives for early completion, and C represents future rehabilitation and user delay costs associated with a particular alternate. The process uses traditional life cycle cost analysis (LCCA) concepts to transfer future rehabilitation and user costs to present time during the performance period. In this model, the lowest bidder determines which pavement type to be selected. This process requires the agency to consider future costs of rehabilitation, traffic control, and user delays costs. A 25% threshold value in the difference of LCCs was adopted to establish a reasonable interval in which pavement systems are likely to compete. In case the difference in LCC of competing pavement types is larger than 25%, the alternate with the higher LCC will be removed without entering the bidding process. By comparing the lowest bid prices with the estimated costs calculated by LADOTD the research has also concluded that using ADAB model suggests a trend toward reduced contract bid prices, possibly because of added competition [1]. The activity timing for future rehabilitation is based on Table 2.2.

Table 2.2 Scenarios for Future Pavement Rehabilitation [1]

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	N/A
	Flexible	New AC Overlay	Cold Plane & Overlay	No Action	N/A
Interstate New Construction	Rigid	New JPC Pavement	No Action	Clean/Seal Joints Patch 1% of Joints	Retexture Patch 3% of Joints
	Flexible	New AC Pavement	Cold Plane & Overlay	No Action	Cold Plane & Overlay
Other Arterial New Construction	Rigid	New JPC Pavement	No Action	Clean/Seal Joints Patch 1% of Joints	Retexture Patch 2% of Joints
	Flexible	New AC Pavement	Cold Plane & Overlay	No Action	Cold Plane & Overlay

By including concrete and asphalt paving industries early in the process, LADOTD has increased the chance of developing a fair framework. The selection criteria for applying ADAB model is mentioned to be based on annual average daily traffic (AADT), project length, and minimum required concrete pavement thickness but the research does not specify more details about selection criteria. It also lacks explanations about the procedure of checking the equivalency of designs or the criteria considered in designing equivalent asphalt and PCC pavements.

The Michigan Department of Transportation (MDOT) has developed recommendations for alternate pavement bidding process for M-6 South Beltline Project in Grand Rapids, Michigan [6]. MDOT uses actual historical data to develop maintenance and service life lengths for the pavements and pavement maintenance strategies in order to conduct LCCA. The equivalent pavement designs are determined by using 1993 AASHTO Guide for Design of Pavement Structures. The user delay costs associated with the various maintenance procedures are also considered in LCCA through lane rental calculations. The pavement type selection is determined based on the lowest Equivalent Uniform Annual Cost (EUAC). MDOT has also developed a procedure for incentive payment for extraordinary pavement performance. This incentive is based on the savings realized by the increased service life exhibited by the pavement. In this model MDOT provides pavement designs and a method of determining LCCs for each pavement design. It was determined in the pre-bid meetings that the best approach to providing for alternate pavement bidding was to bid the pavement portion of the M-6 projects separately. The paving contract will only involve the final preparation of the subgrade surface and the paving of the roadway [6].

The bids were evaluated by MDOT personnel and it was found out that despite the fact that there are savings over the engineer's estimate it is impossible to predict whether these savings will be realized on future Alternate Bid projects. Although both industries have been involved in the process from the beginning, Michigan Concrete Pavement Association expressed some concerns about the equivalency of the two pavements. Also the cost effectiveness of the process cannot be determined until an evaluation can be made of the long-term pavement performance and maintenance costs of alternate bid projects versus those of traditional approach [6].

Missouri Department of Transportation (MoDOT) believes that alternate bidding provides an opportunity for both asphalt and concrete contractors to bid on a single project which translates more competition and ultimately lowers cost to the taxpayer. On the other hand for unique working conditions or very high traffic volumes alternate bidding may not be the right solution. MoDOT reported that two major negative aspects of alternate bidding identified were a) disagreement by the pavement industries over design-life assumptions and b) extra work required to design plans and to compute bid quantities for two pavement types. The LCCA and assumptions are believed to have major effects on the alternate bidding process. Maintenance costs were not included in the analysis and salvage values were assumed to be equal because of lack of historical data. Also user cost could not be considered because of the limited knowledge of its impact on LCCA. The problems including user costs in LCCA are first, it is difficult to estimate the time of delays and to place a cost on those delays, and, second, user savings do not come back into the budget to supplement the extra expenditures associated with reducing user costs [2].

Pavement Type Selection (PTS) in MoDOT has been used primarily to decide the design process usually three to five years in advance of the award of a project. The research team directed their efforts towards identifying a PTS process that determine LCCs closer to the time of the letting of a project in order to reflect current costs as much as possible. The new PTS process is shown in Figure 2.1. MoDOT utilizes the modified International Roughness Index (IRI) to evaluate the new pavement designs as shown in Table 2.3 [2].

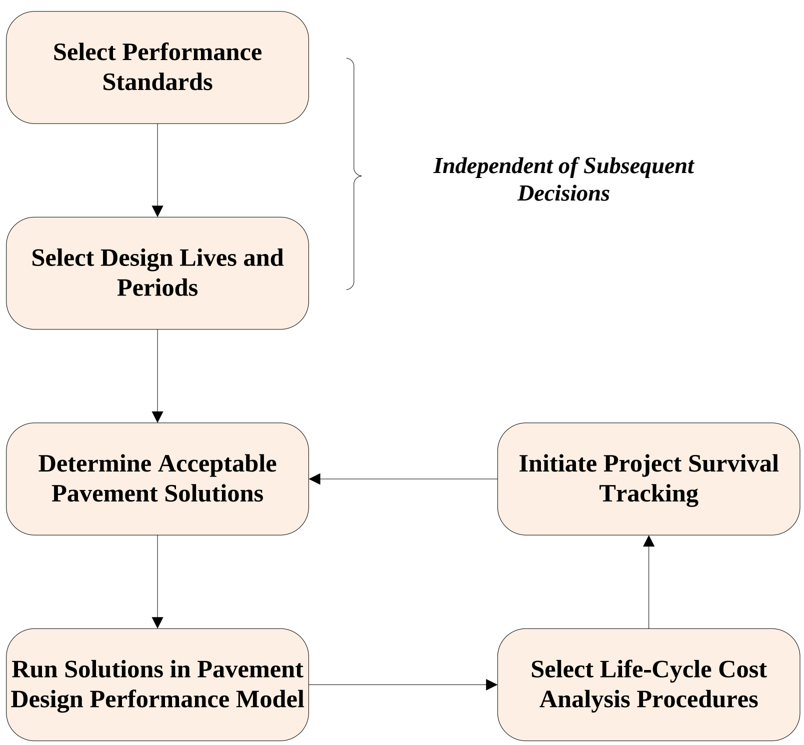


Figure 2.1 Pavement Type Selection Process [2]

Table 2.3 Recommended IRI (inches/mile) Percentage Ranges [2]

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

Recommended survival histories of full-depth hot mix asphalt (HMA) and Portland cement concrete (PCC) pavements in Missouri, obtained from MoDOT's pavement management database, are provided in Table 2.4. Also design life assumptions utilized by other regional states are shown in Table 2.5.

Table 2.4 Recommended Design Period Expectations for Existing Treatments [2]

Initial Construction	**Design Life**	**When**	**Future Rehabilitation Required During Design Life**
Full-Depth HMA Pavement	45 Years	20 Years 33 Years	Mill 1 3/4" and replace in kind, traveled way only (24'). Mill 1 3/4" and replace in kind on entire pavement width, including shoulders
PCC Pavements	45 Years	25 Years	Diamond grind traveled way (24' wide) and perform full depth pavement repair (assume 1.5 percent of traveled way).
Unbonded PCC Overlay	45 Years	25 Years	Diamond grind traveled way (24' wide) and perform full depth pavement repair (assume 1.5 percent of traveled way).

Table 2.5 Other State’s Extended Design Life Expectations [2]

State	Design Period (yr)	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

Based on the review of the five alternate bid projects accomplished in MoDOT the report concludes that negative aspects could be solved and alternate bids on pavement is an excellent tool for achieving the lowest cost for the longest life. Also the representatives from concrete and asphalt industries believed that although the design life assumptions are not a place of agreement, the alternate bid provided an opportunity for their pavement type to be selected. In addition, in alternate bids the comparison between material and construction costs are truer than the existing PTS process which is based on the cost comparisons of 3-5 years before letting the project.

Smith and Fund [7] believe that LCCA as part of the alternate bid process provides government agencies with better knowledge of the true cost of a roadway rather than just considering the initial cost of the pavement. They define the followings as key points to consider in a LCCA:

1. Use of equivalent Asphalt Concrete Pavement and PCC pavement design sections.
2. Selection of accurate maintenance and rehabilitation activities for both pavement types
3. Selection of appropriate discount rate.
4. Inclusion of user costs such as a user delay and accident costs.
5. Inclusion of sustainability of pavement type.

Nine alternate bidders across Canada since 2000 have been studied to assess the efficiency of this type of bid process. Only maintenance and rehabilitation costs are included in LCCA. The results show concrete pavement structures can be competitive with asphalt pavement structures when bidding equivalent pavement designs with LCCA components. Also the research indicates that using alternate bids increases competition and enables government agencies to pave more roadways with the same amount of money [7]. This study lacks involvement of the Asphalt concrete industry which might have led to a biased conclusion because of unequivalent designs. Also the cost effectiveness of the process needs to be checked in long-term in order to take actual rehabilitation and maintenance costs into consideration.

The Kansas Department of Transportation (KDOT) has published their experience in using the alternative bidding process in a highway construction project. One of motives of KDOT in applying alternative bidding process is to ensure the agency obtained the least cost alternate where the LCCA shows the surfacing alternates to be very close in cost. Also this process involves both asphalt and concrete industries in selecting the pavement type which helps to eliminate possible biases in the current process. For LCCA, only future rehabilitation activities are included in the calculations while user cost and maintenance cost are not taken into consideration. After the bid process, it was found out that LCCA adjustment did not determine the low bidder. Also the contractor with the lowest surfacing bid was not the winning contractor. The lowest surfacing cost for all the surfacing on the project was submitted by the third lowest bidder which was 6.5% lower than the winning bidder and 11.4% lower than the PCC pavement bidder. Although letting the whole project over one bid has avoided KDOT to select the best pavement type, the contractor survey indicates little support for letting the project by separate work type. Only one in ten contractors felt the bid package treated each alternate equally. Due to the fact that contractors utilized subcontractors, primarily in grading and bridges, in preparing their bid, this report concludes that KDOT should consider letting separate contracts for the grading, bridges, and surfacing [8].

Unlike Kansas Department of Transportation, Indiana Department of Transportation (INDOT) believes that using their process of alternate bids for pavement type selection has been very successful. Through INDOT US31 experimental project, the alternate bid process involved two distinct sets of bids on one project, one for Hot Mix Asphalt (HMA) pavement and one for PCC pavement. This enabled contractors who work with both types of pavements to bid on both contracts resulting in more competition and cost saving in the process. Asphalt and Concrete industry representatives were contacted after the project was awarded. Their comments are as follow [9]:

1. The Contactors want the present worth cost published before bid opening so they can factor in their bid amount.
2. Some Contractors commented that there are far too many maintenance activities such as joint seals every 3 years on HMA pavement.
3. Some Contractors want to have alternate pavement options for Shoulders also.

Although many contractors asked present worth cost to be published before bid opening, INDOT has concluded not to publish those costs on future alternate bids due to the possibility of unbalanced bids. It is also mentioned that INDOT is not able to compare whether this process is most economical or whether this process promotes more competitive bid prices [9].

In the pavement type selection policy prepared by the Kentucky Transportation Cabinet (KYTC), alternate pavement bidding procedure has been recommended in the situations where alternative pavement designs have comparable costs and there are no overriding engineering factors favoring one alternate. Two pavements are considered comparable costs as long as the life-cycle costs are within 20 percent. Based on the process of KYTC, a bid adjustment will be used in the bidding process which would consider future agency costs calculated by LCCA with the discount rate of 4%.

When the user costs during initial construction are calculated to be greater than $2,000,000 for either alternate, a time component (B) may be added to represent the effects of user costs in alternate pavement bidding process. The B component is the number of calendar days necessary to complete all work associated with a project multiplied by the daily user cost.

The following formula is used for alternate bidding with a time component [10]:

$$Total\ Bid = A + B + C$$

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

In April 2008, Gilbert Newman, a state highway engineer at KYTC, reported the evaluation of alternate pavement bidding to FHWA. This report indicates that the use of alternate pavement bidding in select areas in the state increases the number of bidders. Consequently overall bid prices will be reduced through competition creating a cost savings to the Cabinet. In addition, it is indicated in this report that for the two projects that attracted both asphalt bidders and concrete bidders, the difference in the overall low asphalt and low concrete bids were greater than the difference in the bid adjustments by LCAA. Therefore, it is inferred that while the bid adjustments did play a role in the process they did not actually determine which contractor was the lower bidder [11].

Texas Transportation Institute published a technical report in August 2009 regarding the considerations for rigid vs. flexible pavement design when allowed as alternate bid. In the literature review the factors involved in the comparison of pavement designs and pavement type selection were identified. In addition, the issues faced by Texas Department of Transportation (TxDOT) in generating alternative designs were pointed out through interviews with three major Districts, Construction Division, and Design Division. General guidelines currently used by TxDOT regarding the design of pavement alternates for new construction and reconstruction projects are to [5]:

- 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.

Then a side-by-side comparison of pavement designs was conducted using TxDOT design procedure. It has been suggested that the data inputs for both rigid and flexible pavement designs must first be standardized in order to develop equivalent designs. Therefore design parameters such as present serviceability index, reliability, standard deviation, environmental effects, traffic projection, and maintenance and rehabilitation were standardized. Based on four traffic levels, three environmental condition, and two subgrade support condition, 24 factorial designs were generated for both types of pavements out of which seven cases for flexible pavements and three cases for rigid pavements were considered for side-by-side comparison. Then three flexible pavement and one rigid pavement structures were selected for further life cycle cost analysis. Figure 2.2 and Figure 2.3 show a summary of the costs in dollars per lane mile excluding user costs with a 4 percent discount rate and a 7 percent discount rate, respectively.

The pavement structure of case A is 2” of AC, 11” of Asphalt Stabilized Base, and 6” of Flexible Base. The pavement structure of case B is 9.5” of AC, 6” of Flexible Base, and 8” of Lime Treated Subgrade. The pavement structure used in Case C is 9.85” of AC, 4” of Flexible Base, and 8” of Lime Treated Subgrade. The pavement structure used in the rigid pavement is 12” of Concrete Slab, 1” of AC, 6” of Cement Treated Base, and 8” of Lime Treated Subgrade. It is observed that in Case C the best pavement type depends on the discount rate, in case A rigid pavement gives the better cost and flexible pavement in Case B gives the best overall cost. By including user costs, it is inferred that in this case study for intermediate and high traffic the rigid pavement design becomes the alternative with the lowest total life-cycle cost [5].

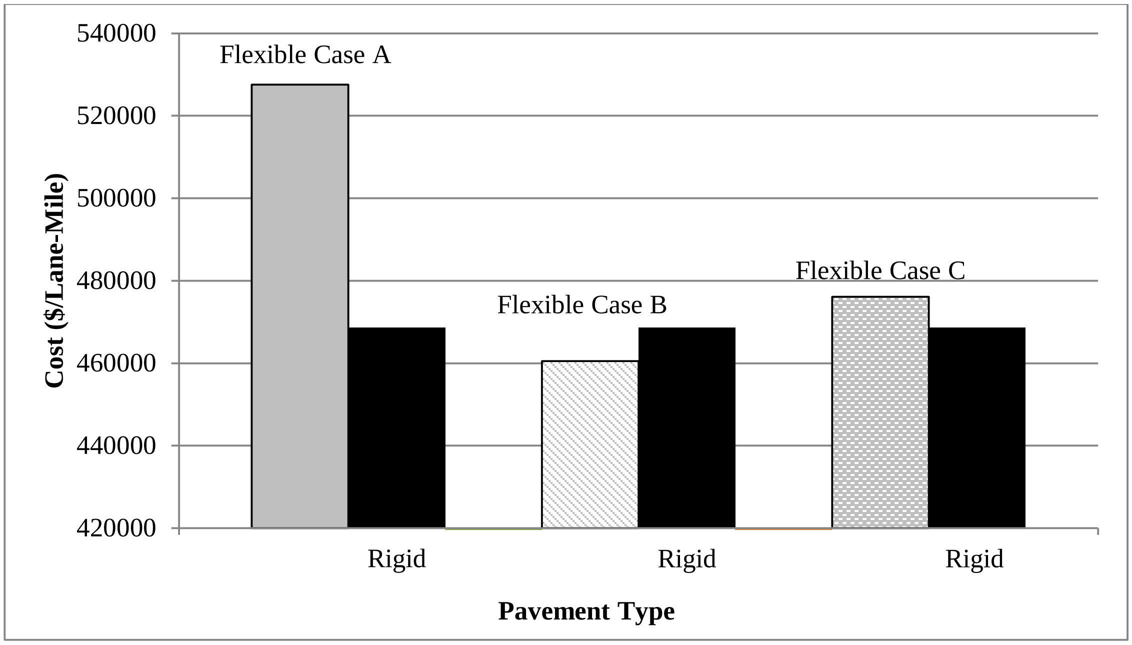


Figure 2.2 Cost Comparison Flexible vs. Rigid Cases with a 4 Percent Discount Rate [5]

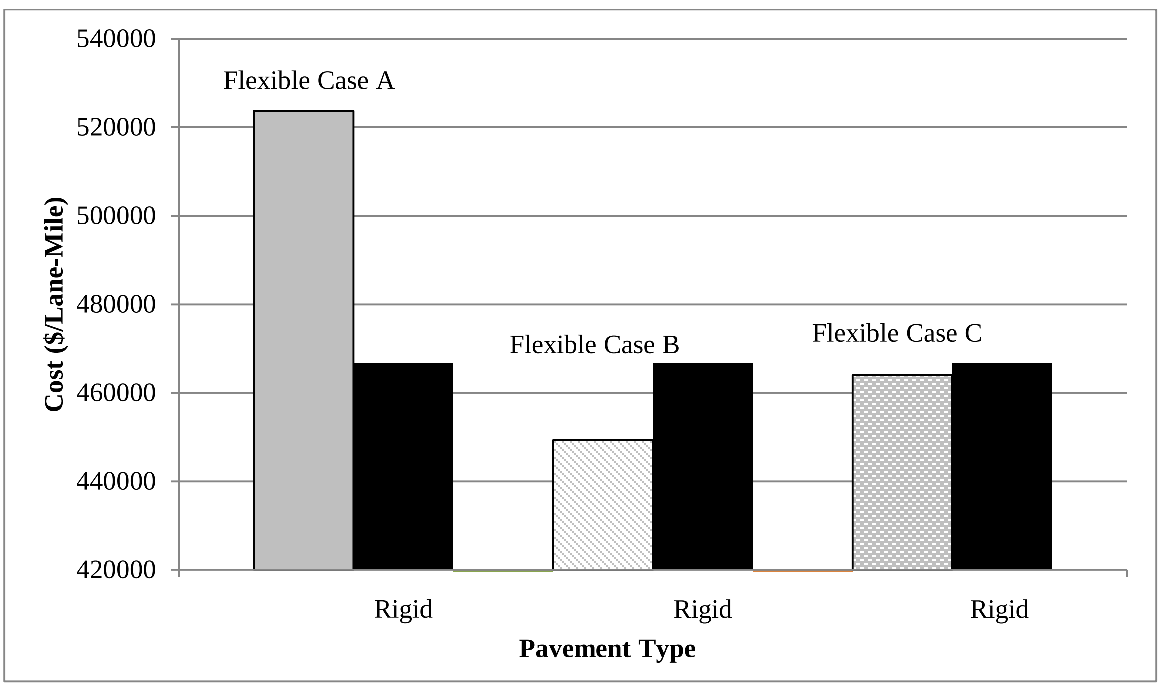


Figure 2.3 Cost Comparison Flexible vs. Rigid Cases with a 7 Percent Discount Rate [5]

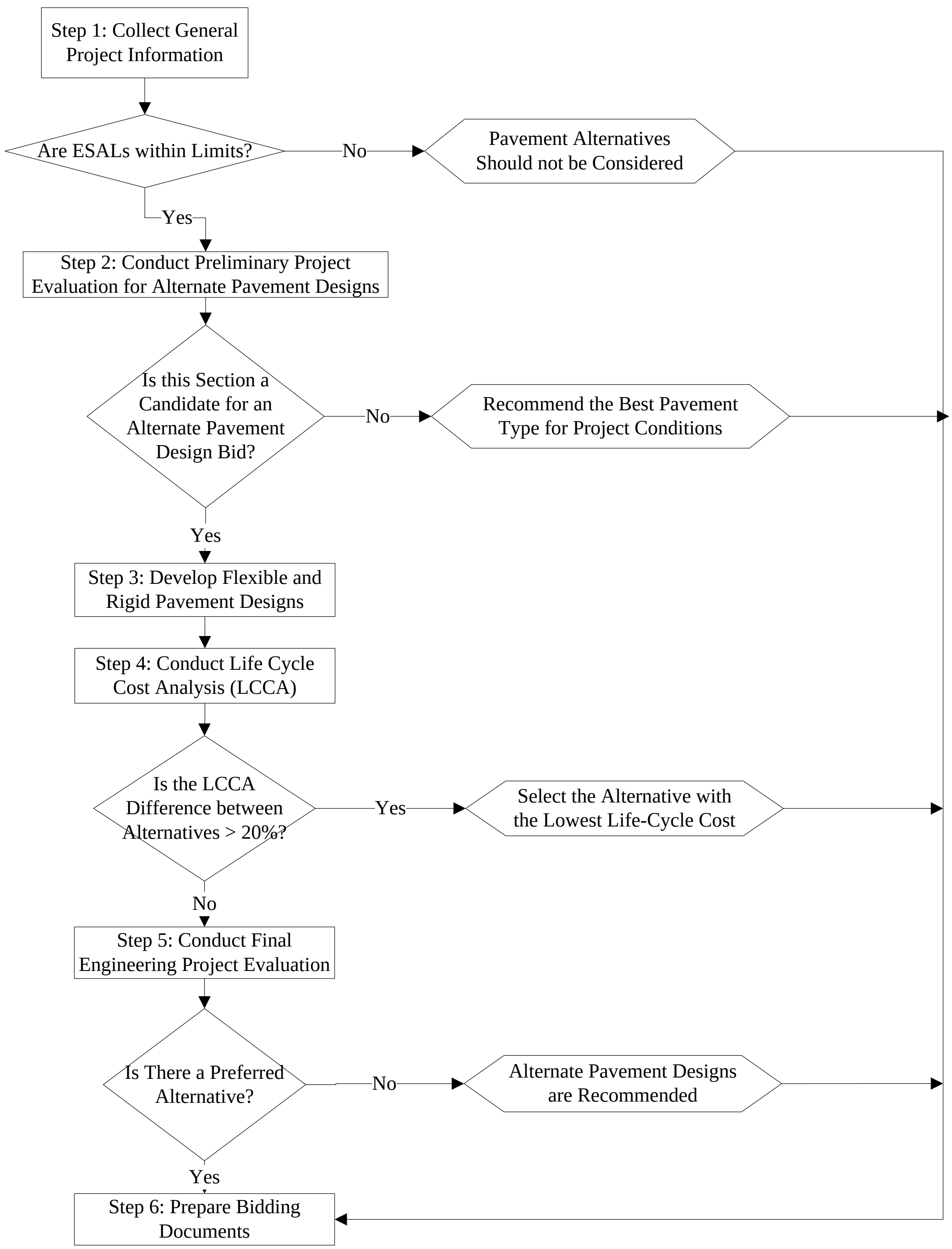


Figure 2.4 Alternate Pavement Design Analysis Flowchart [5]

The most important contribution addressed in this research study would be developing a protocol for determining when to consider pavement alternates. This step by step process is indicated in

Figure 2.4 [5]. During the first step, general information about the project is collected. In the second step, a preliminary project evaluation is conducted based on answers provided to seven questions about:

a) total lane miles of project,
b) construction traffic control difficulties,
c) the total number of bridge structures on the pavement,
d) the total number of driveways,
e) the estimated total project cost,
f) underground utility issues, and
g) subgrade issues.

The recommendation of a project as a candidate for alternate pavement designs is based on the total number of points obtained through answering the questions.

The experience of different transportation departments indicate that using alternate bidding process has been successful in increasing competition by attracting more contractors to participate in the bid process thus lowering construction costs. At the same time most of the transportation officials have mentioned that this process needs to be assessed in the long run in order to make sure that it selects the most economical alternative pavement type.

LCCA has been utilized by all the transportation departments that have applied alternate bid process for pavement type selection. Although the interim technical bulletin published by FHWA in 1998 has provided comprehensive guidelines for LCCA there are differences in the application of LCCA methodology. The differences relate to different assumptions regarding the length of the analysis period, maintenance and rehabilitation timings, inclusion of salvage value, inclusion of user costs, and deterministic or probabilistic approach in the analysis.

Table 2.6 shows a summary of alternate bidding process practices in different transportation departments. As can be seen in this table all of the departments except Kansas DOT and Michigan DOT have reported the application of alternate bidding in the pavement selection process a successful experience. Michigan DOT believes that the success of the process can only

Table 2.6 Experience of Transportation Departments in Applying Alternate Bidding Process

Agency	Features		Method	Constraints	Result
Louisiana DOT	-Trend toward reduced contract bid prices -Selecting the most economical alternative		-LCCA -ADAB Model -"A+B+C"	-AADT -Project length -Minimum required concrete pavement thickness	-Successful
Michigan DOT	-May be able to make savings	-Impossible to predict whether savings over engineer's estimate will be realized in future AB projects -Difficult to agree on equivalency of designs for industries	-LCCA -Lowest EUAC -Incentive for extraordinary pavement performance -Letting pavement portion separately	-Not specified	-Cannot be determined
Missouri DOT	-More competition for both industries and ultimately lower cost -Excellent tool for achieving the lowest cost for the longest life -Competition over truer material cost and construction prices	-Disagreement by the pavement industries over design-life assumptions -Extra work required to design plans	-LCCA	-Unique working conditions -Very high traffic volumes	-Successful -Constraints can be worked out
Transportation Association of Canada	-Provide government agencies with better knowledge of the true cost of a roadway -Increases competition -Enables government agencies to pave more roadways		-LCCA	-Not mentioned	-Successful -Concrete pavement structures can be competitive with asphalt pavement structures

Table 2.6 Experience of Transportation Departments in Applying Alternate Bidding Process (Cont'd)

Agency	Features		Method	Constraints	Result
Kansas DOT	-Agency obtained the least cost alternate -Helps eliminate possible biases in the current process	-LCCA adjustment did not determine the low bidder	-LCCA -Letting the whole project on one bid	-Not specified	-Not successful -Separate contracts are recommended
Indiana DOT	-More contractors participated in the bid -More competition -Cost saving	-Not able to compare whether this process is most economical or promotes more competitive bid prices	-Two distinct sets of bids -LCCA -Present Worth not published before bidding	-Not specified	-Very successful
Kentucky Transportation Center	-Increased numbers of bidders -Increased competition -Lower overall bid prices	-Bid adjustment did not affect the award of the project	-LCCA -A+B -A+B+C for projects with initial cost of over $2,000,000	-Can be applied when costs are comparable and there are no overriding engineering factors favoring one alternate	-Successful in select areas in the state
Texas DOT	-Is able to attract more contractors -Increases competition -Lower construction costs		-LCCA -Specifying situations that alternate bidding can be applied	-Pavement widening projects -Process does not involve new construction -Pavement is less than 500 feet in length -Pavement is less than 5 miles in length and both connecting pavements are either rigid or flexible pavements -There are areas where truck traffic will be stationary for long periods of time Project's one time traffic ADT value range is below 300 or above 2,000 -Concrete pavement thickness from 1993 AASHTO Guide design procedure is less than 8 inches or 12 inches and greater	-In case applied on right projects helps in selecting a better alternative -Use of LCCA is recommended -Using FHWA RealCost software is recommended for LCCA

be determined in the future when the actual costs of maintenance and rehabilitation activities and user costs are known. On the other hand Kansas DOT has not been successful in the alternate bidding process since they have let the whole project in one set of bid and this has led to selection of the alternate bid with the third lowest surfacing price. They recommend using separate contracts for grading, bridges, and surfacing.

It can be inferred from the experiences of transportation departments that alternate bidding can only be applied in certain situations. Texas DOT has provided the most comprehensive guideline for determining when to consider pavement alternates. Since the situations are different in each state the necessity of developing such guidelines for other states seems inevitable.

Two states of Louisiana and Kentucky have suggested the use of A+B+C bidding model. Unlike Louisiana that incorporates “B” in all the alternate bidding projects, Kentucky restricts the inclusion of “B” to projects that have the user cost of more than $2,000,000 for both flexible and rigid pavements.

A review of alternate bidding experiences reveals that this project procurement method can result in cost savings during the life-cycle of pavements. However, lack of certainty in prediction of future maintenance and rehabilitation activities has created a situation where asphalt and concrete industries question the integrity of life-cycle cost models developed for rigid and flexible pavements. Since the result of alternate bidding procedure is dependent on the accuracy of life-cycle costs calculated for rigid and flexible pavements, LCCA is critical in the success of alternate bidding procedure.

2.4 Life Cycle Cost Analysis

Economic considerations are very important in highway construction projects. Economic feasibility is the essential requirement of successful engineering application. DOT engineers are confronted with two important interconnected environments: the physical and the economic [12]. Their success in designing highway systems depends on knowledge of physical laws. However, the worth of these products and systems lies in their utility measured in economic terms [12]. As can be seen in Figure 2.5, more than half of the projected life-cycle cost is committed by the end of the system planning and conceptual design, even though actual expenditures are relatively minimal by this point in time [12].

In the traditional bidding process, the initial construction cost is the only parameter considered to determine the winner. However, pavements are designed to function for a long period of time, and during their life-cycle, pavements go under various types of maintenance and rehabilitation activities. Therefore, a large initial construction cost may end up being the most economical solution in the long run. In alternate pavement type bidding, the owner incorporates the life-cycle costs of different types of pavement in the bid process. The winner is the contractor that has the lowest total combined bid which is the summation of bid price and life-cycle cost. This helps owners to account for the difference between the life-cycle costs of different pavement types in order to select the most economic scenario in a long period of time. The same process can be used to determine the most economical rehabilitation type in terms of life-cycle cost. This allows the pavement type and the rehabilitation type to be selected through the competition during the bid process. Anderson and Russell [13] believe that the ideal quality parameter would be derived from a performance-related model such as a LCC. Although a high quality product increases the initial construction costs, its durability results in lower future maintenance and rehabilitation activities. Therefore, a high quality product might end up being a more economical solution with a lower LCC. In other words, relying on contracting methods or bidding solutions that minimize the LCC instead of initial construction cost can guarantee the quality of product as well.

Clemson University published a comprehensive technical report in April 2008 regarding the life-cycle cost analysis in pavement type selection. This study is based on the analysis of data obtained from a survey of states across the U.S. and provinces across Canada. The goal of this research was to develop a probabilistic-based LCCA approach that is customized for South Carolina utilizing the practices of other states. Also, specific recommendations on a range of values for different input parameters based on the survey data are made. In addition, RealCos software developed by FHWA was found to be widely used by several state agencies and is the most comprehensive tool in its treatment of different input parameters. Further, FHWA has been helpful in providing support to customize the software to meet each individual state’s needs.

Based on the findings, RealCost software was proposed as preferred software of use with conducting LCCA for pavement-type selection [14].

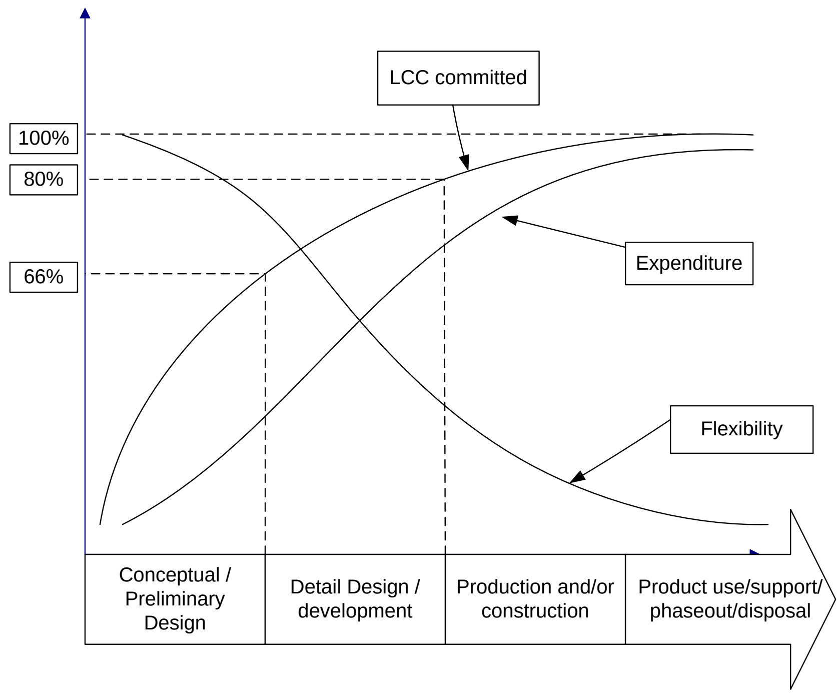


Figure 2.5 Life-Cycle Cost vs. Flexibility of Projects [12]

In the final survey conducted by Clemson University a total of 24 agencies responded. 92% of these agencies (22 agencies) used LCCA for pavement type selection except Maine and British Columbia which indicated that they only have flexible pavements. Out of 22 states that practice LCCA for pavement type selection and responded to the final survey, 68% of the states (15 states) indicated that they were either satisfied or only had minor concerns with their existing LCCA process and 32% (7 states) indicated that they had significant concerns about the current practice of LCAA for pavement type selection process. The specific concerns raised by these states are [14]:

- Unreliable quality of the input data into LCCA models.
- Lack of adequately trained individuals who understand the importance and implication of the input parameters into LCCA programs such as RealCost.

- Difficulty in predicting cost of materials in a period of rapidly fluctuating prices to get a reliable and accurate LCCA.
- Lack of long-term field performance data for newer asphalt and concrete pavement designs and materials.
- Lack of rational and predictable triggers for conducting rehabilitation and maintenance activities.
- Disagreements with the asphalt and concrete pavement industries about the most appropriate inputs such as the determination of the timing of future rehabilitation, selection of unit costs, and determination of salvage value.
- Lack of confidence in the LCCA process due to substantial differences between the initial construction costs of asphalt and concrete pavements [14].

In response to the type of LCCA approach only 5% of the responding states (1 state) used a probabilistic approach for all projects. Approximately 81% (17 out of 21) of the agencies responding to the survey still used a deterministic approach. In addition, the initial and rehabilitation service lives of PCC and AC pavements have been asked from the transportation officials. A summary of the results of the survey are shown in Appendix A.

When asked the question of including salvage value in LCCA calculations, 10 state DOTs out of 23 state DOTs that responded to this question, indicated that they always include salvage value in their calculations. The summary of principal findings is as below:

- Almost 92% of the survey respondents are using LCCA for pavement type selection.
- Cost, pavement structure, and the network level of the pavement in the system were reported by many states to be the major criteria that would trigger the requirement to conduct LCCA.
- Over 50% of the responding agencies use RealCost, DARWin, or some customized software to conduct LCCA.
- Almost 60% of the states do not consider any type of user cost in their approach to LCCA. The states that include user costs into the analysis, consider only work zone user delay costs.
- Most of the states use a 4% discount rate.

- Majority of state DOTs use historical data from pavement management system to determine their rehabilitation timings.
- About 56% of the respondents include salvage value in their analysis.

Chapter 3 ALTERNATE BIDDING PROJECT SELECTION PROCESS

3.1 Introduction

Alternate pavement type bidding is a procurement process in which the type of pavement is determined by the contractor that proposes the lowest bid. In this procurement method, the owner provides contractors with feasible pavement design packages, calculates life-cycle cost for each design, and includes them in the bid documents. Contractors evaluate the alternatives listed in the bid package and select the pavement type that maximizes their chance of offering the most competitive price. The owners include an adjustment factor in the bid package which accounts for the differences in future cost of alternatives. Therefore, the alternate pavement type bidding can be considered a pavement type selection procedure. Instead of selecting the pavement type during the design process, owners let contractors compete over the pavement type. This results in selection of the pavement type with the lowest total life-cycle cost.

3.2 AASHTO & FHWA Recommendations

The AASHTO Guide for Design of Pavement Structures [15] has envisioned the first steps needed to help the national pavement community move toward alternate bidding by theorizing that perhaps someday, agencies could successfully select between asphalt and concrete pavements based on the true total cost. This vision is rephrased in the 1993 version of the Guide which states the ideal goal of pavement type selection:

> “If all engineering factors could properly be modeled and all costs properly compared and discounted to present value, the ultimate lowest cost pavement of whatever type or design would be the proper pavement to construct.”

However, pavement models are not perfect and all costs cannot be properly compared and discounted to present value. This is recognized by the Guide with the following paragraph:

“The selection of pavement type is not an exact science, but one which the highway engineer or administrator must make a judgment on many varying factors such as traffic, soils, weather, materials, construction, maintenance, and environment.”

Therefore, both FHWA and AASHTO have emphasized the importance of considering subjective considerations during the pavement type selection process. This is to ensure that the designs are equivalent and none of the pavement types are preferred over the others before an alternate design is included in the alternate pavement type bidding process. There are situations where a pavement type technically dominates other alternatives. In these situations, the owner needs to select the preferred pavement type before the bid competition starts and should not let the pavement type to be defined solely by competition between contractors.

AASHTO’s guidance on pavement type selection [16] outlines the pavement selection process, as shown in Figure 3.1. As can be seen in this figure, two lists of factors influence the decision making process:

a) principal factors
b) secondary factors

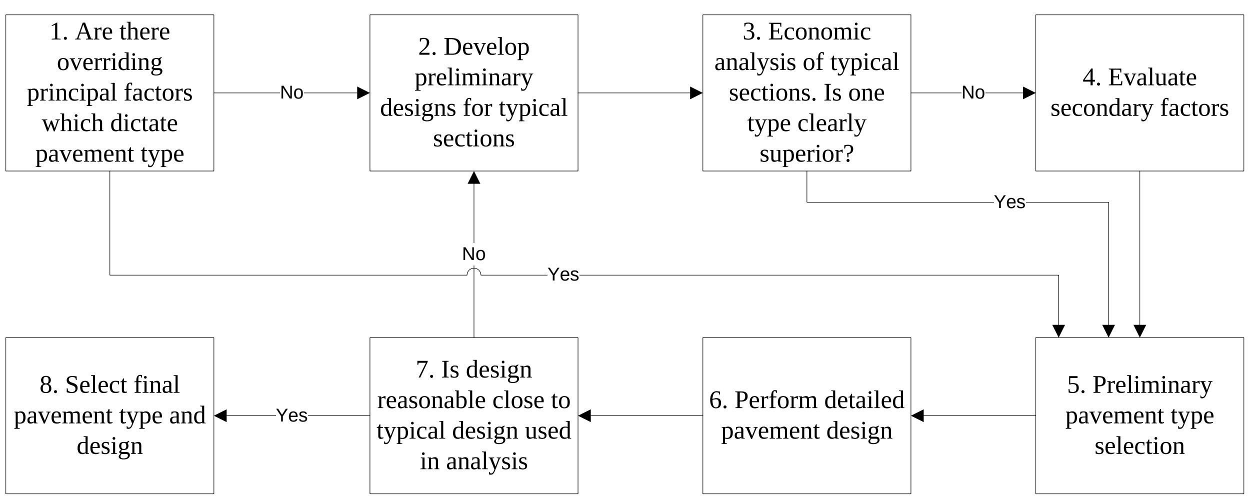


Figure 3.1 Pavement Type Selection Process [16]

Principal factors are those factors that have a major influence and may dictate pavement type in some instances. Secondary factors are those factors that have lesser influence and are taken into account when principal factors are not overriding any pavement type or one type is clearly not superior from an economic standpoint. The principal and secondary factors are summarized in Table 3.1.

Table 3.1 AASHTO's Principal and Secondary Factors Influencing Pavement Type Selection

Principal Factors	**Secondary Factors**
• Traffic • Soils characteristics • Weather • Construction considerations • Recycling • Cost comparison	• Performance of similar pavements in the area • Adjacent existing pavements • Conservation of materials and energy • Availability of local materials or contractor capabilities • Traffic safety • Incorporation of experimental features • Stimulation of completion • Municipal preferences, participating local government preferences and recognition of local industry

3.3 Pavement Type Selection Procedures

The pavement type selection processes adopted by State Highway Agencies can be categorized into four different groups.

1. Alternatives are developed and LCCA is performed. If the life-cycle costs of alternatives are within a set range, the life-cycle costs are considered equivalent. Then the pavement type is selected by using subjective factors. If life-cycle costs are not equivalent, then the alternative with the lowest life-cycle cost is selected.
2. Each alternative is first evaluated utilizing subjective considerations to determine if it meets the engineering criteria for the project site. The preliminary designs are developed for the alternatives that satisfy the engineering criteria and LCCA is performed. The design with the lowest life-cycle cost is selected.
3. This process is like the second group; however, after performing LCCA projects are checked based on their traffic level and length. If they are more than a certain threshold, both rigid

and flexible designs are prepared and the pavement type is selected through and alternate bidding process. In the case of Ontario, for projects longer than 10 lane km and annual equivalent single axle load repetitions expected to be larger than 1,000,000 within the next 4 to 5 years, pavement type is selected by alternate bidding.

4. Pavement type selection is only based on LCCA results. Alternatives are developed and LCCA is performed. The alternative with the lowest life-cycle cost is selected.

In the first group, the LCCA is performed for all the alternatives including those that do not satisfy engineering criteria. Since the amount of effort required to do LCCA is more than subjective evaluation of alternatives, it would be beneficial to filter the alternatives utilizing subjective considerations and perform LCCA for all the alternatives that meet the engineering criteria. In the second process, the alternatives are first evaluated using subjective considerations. However, checking the secondary factors before performing LCCA, would result in the elimination of some alternatives that do not satisfy engineering criteria but are economically superior. Based on the AASHTO guide, secondary factors are not required to be checked if an alternative is economically superior. The third process which is only based on LCCA results can also result in the selection of an alternative that is economically superior but does not satisfy the principal engineering criteria. Therefore, the best scenario would be checking the alternatives to see whether there is an overriding principal factor that dictates a pavement type. Then evaluate the alternatives based on their life-cycle cost. If none of the alternatives are economically superior, then the pavement type needs to be selected by considering the secondary factors.

Now what if a pavement type is not clearly superior when considering principal, economic, and secondary factors? According to FHWA, in this situation the alternatives can be considered as having equivalent designs. The FHWA defines equivalent design as designs that perform equally, provide the same level of service, over the same performance period, and has similar life-cycle costs. Therefore, prior to alternate bidding, alternative designs should go through the pavement type selection algorithms to make sure that they are truly equivalent designs. The process illustrated in Figure 3.2 is proposed for pavement type selection. The output of this process is either selection of a clearly superior alternative or determination of alternatives with equivalent designs. The alternatives should go through this process before being included in alternate pavement type bidding process.

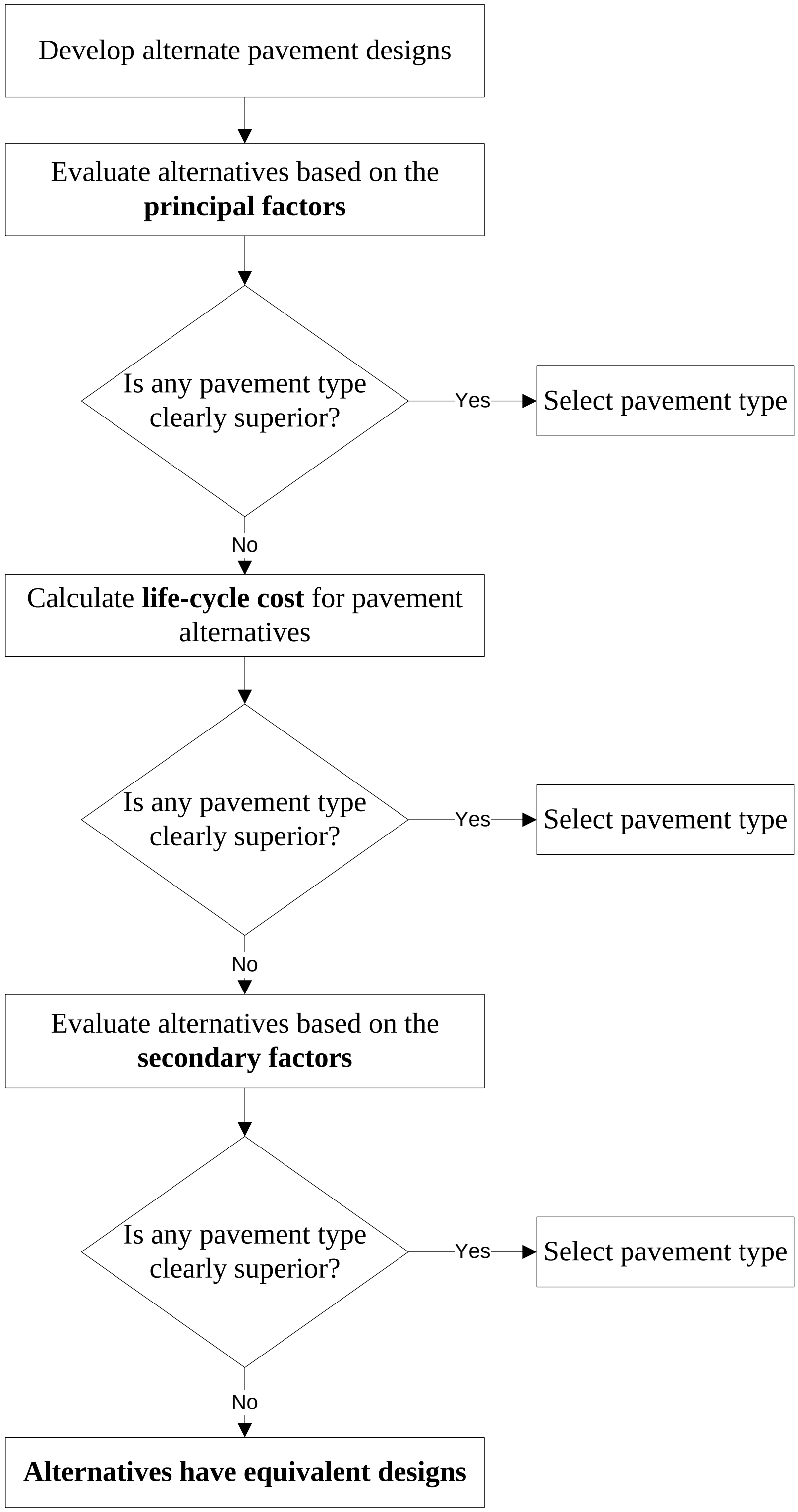


Figure 3.2 Proposed Pavement Type Selection Procedure

3.4 ODOT Pavement Type Selection

The subjective considerations have been briefly defined by AASHTO guide; however, the engineering factors considered in each state are different. In ODOT, the pavement design engineer performs pavement design analysis and develops both flexible and rigid pavement designs for each project. The pavement design analysis is based on the project information such as project scope, traffic data, preliminary plans, and soil report. If the design process is in the house, then the roadway design team develops the typical sections based on the designs. These typical sections include the schematic of typical sections showing layers and thicknesses and geometrics of each section as well as the pay items for each pavement type, associated quantity and unit price, and the cost of each pavement type in terms of dollar per linear foot. The quantities of material are defined based on the geometry of the sections and the unit prices are estimated based on the price history in the region. Once pavement design is complete, the ODOT Pavement Design Engineer prepares a pavement recommendation for submission to the division engineer, which includes:

a) Rigid and flexible pavement design alternatives with estimated cost comparisons;
b) Information on pavement type and availability of materials;
c) Recommended pavement design alternative

Then the design packages as well as the pavement design engineer's suggestion regarding the type of pavement are sent to division engineers. The division engineers review the design package and evaluate it based on their own sets of criteria. They have more updated information from the region and are more aware of the activities going on in the region. If division engineers have specific adjustments and modifications to the design, they send the package back to the pavement design engineer and the suggested modifications will be discussed with the roadway division engineer. Otherwise they select the pavement type based on the suggestion of pavement design engineer. However, the final decision is made amongst the pavement division engineer, the roadway division engineer, and the division engineer. They use their own sets of criteria when choosing between different pavement types. In other words, they have a sense of what would be the best pavement type for a specific project by relying on their experience. These criteria include:

a) Percentage of truck traffic
b) Average daily traffic of road
c) Location of project (whether it is located in an urban or rural area)
d) Availability of material in the region
e) Strength of concrete or asphalt industry in the region
f) Type of pavement in the adjacent road sections

For roads with high level of traffic and heavy loads such as semi-trucks, concrete pavements are of more preference than asphalt pavements. On the other hand, asphalt pavement is preferred in remote areas with light traffic loads. In urban areas where maintenance activities create significant negative impact to the traveling public, rigid pavement is preferred over flexible pavement. Division engineers also have their own preferences regarding the type of pavement in their region. For instance, in regions with active asphalt contractors, division engineers tend to select the flexible pavement since they believe that the necessary equipment and expertise needed to do an asphalt job is already available in the region.

Currently ODOT only considers the initial construction costs during the pavement type selection process. The future maintenance and rehabilitation costs are not considered in determining the most cost efficient pavement type. Although LCCA is a great tool for pavement type selection, the lack of a system that both asphalt and concrete industries have consensus on has been the main obstacle for implementation of LCCA in ODOT. However, ODOT engineers use their expertise to select the most economical pavement alternative in the long run.

3.5 Questionnaire Survey

In order to determine the subjective factors that needs to be considered in decision making in ODOT, a questionnaire survey was conducted among the study advisory group members as well as division engineers (see Appendix B). A list of factors that might affect the decision making in ODOT was developed through interviews with ODOT pavement design engineers (Jeff Dean and Ezat Sultani), and studying research performed by Wimsatt et al. [5], AASHTO's guidance on pavement type selection, FHWA's clarification on bidding alternate pavement type on the

National Highway System, and the inputs provided by the Study Advisory Group (SAG). The followings are the main literature used in preparing this questionnaire survey:

- Considerations for Rigid vs. Flexible Pavement Designs When Allowed as Alternate Bids by Wimsatt et al. performed by Texas Transportation Institute and Sponsored by Texas Department of Transportation in 2009.
- Neutral Third Party; Ohio Pavement Selection Process Analysis prepared by ERES Consultants Division of Applied Research Associates, Inc. in 2003.
- Pavement Design and Type Selection Process of Missouri Department of Transportation prepared in 2004.
- Agency Process for Alternate Design and Alternate Bid of Pavements by Temple et al. in 2004 which elaborates the alternate bidding procedures in Louisiana Department of Transportation.
- Clarification of FHWA Policy for Bidding Alternate Pavement Type on the National Highway System in 2008.

Using the list of potential factors influencing the pavement type selection process as well as additional questions regarding the parameters required for LCCA, a draft of questionnaire survey was prepared. The questions were discussed at a meeting with study advisory group members. Consequently, 10 questions were added based on their suggestions about the important factors to select projects for alternate bidding. The questionnaire was finalized once the study advisory group members provided their feedback regarding the relevance of questions. The finalized questionnaire consists of 35 questions. The final questionnaire has been reviewed by the SAG members to ensure that the questions are relevant and all the possible factors are included. The responders were asked to provide their opinions about the importance of each factor in decision making. Also a section was added to the end of the questionnaire which asked the respondents to list other significant factors in selecting the alternate bidding projects and rank them based on their level of importance.

Questions have been grouped into ten categories as:

a) Initial Cost

b) Constructability
c) Project Scope
d) Design
e) Operation
f) Utility Issues
g) Sustainability
h) Traffic
i) Payment Method
j) Life Cycle Cost Analysis (LCCA).

In some questions the level of agreement to each statement is asked which is based on a typical five-level Likert scale (1=strongly disagree, 2= disagree, 3=not sure, 4=agree, 5=strongly agree) while for other questions the responder needs to select a value or a range from the suggested options or specify it if it is not included. Responders are also asked to provide additional significant factors or subjective considerations for pavement type selection based on their knowledge and expertise at the end of the questionnaire survey.

The questionnaire survey forms were sent to the members of study advisory group by email. Additionally the research team also requested from the respondents to forward the questionnaire survey forms to experts they feel that need to get involved and contribute to this study. The questionnaire was also forwarded to all division engineers to get their feedback as one of the parties influencing the pavement type selection process.

The research team received ten responses to the questionnaire survey (6 responses from SAG members and 4 responses from division engineers). In other words, we received feedback from all the stakeholders deemed to be relevant in pavement type selection process: ODOT Pavement Design Engineer, ODOT Pavement Management Branch, ODOT Construction Division, FHWA, Asphalt industry, Concrete industry, and ODOT Division Engineers. The overall response rate of this questionnaire survey is 70% which is considered high. This can be due to the fact that a group of respondents have been involved in this research project from the beginning and provided their advices to the research team. It also indicates the high level of enthusiasm to the subject of this research. Figure 3.3 shows a summary of responses to the questions about the level of agreement. The questions are listed on the horizontal axis and the level of agreement to each question is shown on the vertical axis. Blue columns are the average level of agreement and red columns represent the associated standard deviation. The level of standard deviation can be looked as an indicator of uncertainty in the answers. A summary of the responses to all the subjective questions is provided in Table 3.2. A threshold has been defined on the agreement level of 3.5. For responses with level of agreement below this threshold, it is assumed that the majority of responders disagreed that the associated factor should be considered during the pavement type selection process. On the other hand, for responses with a level of agreement above or equal to 3.5, it is assumed the responders agree that the associated factor is significant and needs to be considered in the pavement type selection process.

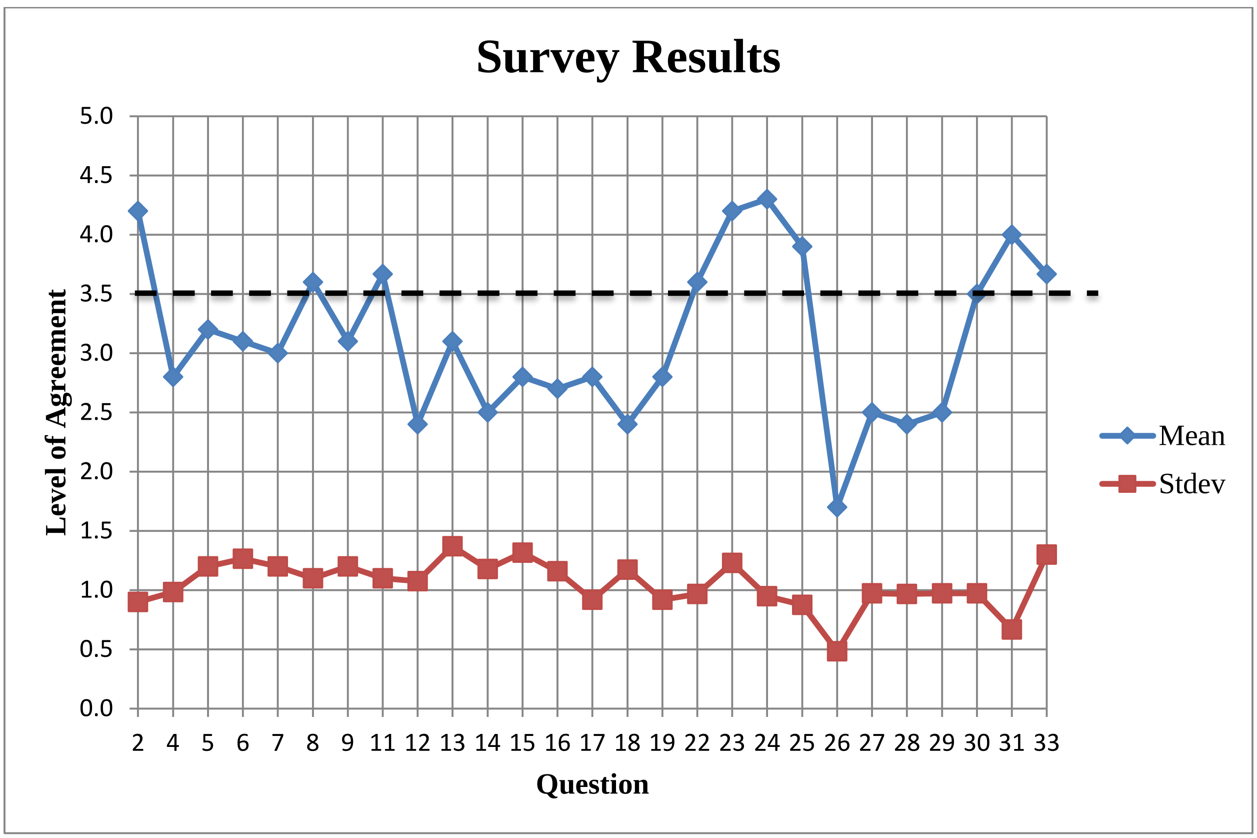


Figure 3.3 A Summary of Answers to the Questions About the Level of Agreement

3.5.1 Significant Factors

The factors with an average level of agreement of 3.5 or more are considered significant factors in selecting the projects for alternate bidding. These factors are related to questions 2, 8, 11, 22, 23, 24, 25, 30, 31, and 33.

In other words the respondents have agreed upon the significance of the following factors:

a) The minimum project cost should be more than a certain amount to use alternate designs in a project.

Table 3.2 A Summary of Responses to the Questionnaire Survey

Question Number	Question	Answer
1	The minimal percentage of difference in construction costs between two alternates in order for them to be considered in alternate pavement bidding.	5.5-10.5%
3	In order to use alternate designs in a project, the minimum project cost should be more than	$7.2 mil
11_1	the minimal project size in order to be considered large enough should be	5.4 lane miles
20	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 controls, would obviously be affected as well. What is your estimate of more time for designers to develop PS&E for pavement alternate projects?	10-30%
21	Alternate pavement designs need to be designed for the service performance of	30 years
32	Heavy truck traffic is called to a situation where percentage of truck traffic in highways is in the following range.	19-24%
34	What should be the percentage of difference in the total LCCs between two alternates in order for them to be considered close enough for alternate pavement bidding?	13%
35	What should be the analysis period for Life Cycle Cost Analysis (LCCA) in order to reflect long-term cost differences associated with pavement alternate designs?	37

This factor is related to question 2. The average level of agreement to the statement in this question is 4.2 with the standard deviation of 0.9.

The amount of the minimum project cost has been asked in the next question and respondents have provided different answers to this question. Three respondents have selected $10 million, two respondents have selected $1 million, one respondent have selected $20 million, and four respondents have selected $5 million as the minimum project cost. Therefore the average minimum project cost would be $7.2 million and projects with lower cost are not suggested to be included in alternate bidding.

b) Concrete pavement is not considered practical where additional lanes or shoulders are to be added to an existing flexible pavement facility.

The level of agreement to this statement has been asked in question 8 which is 3.6 on average with the standard deviation of 1.1. The average level of agreement to this question is not so high and the high standard deviation indicates that the respondents have had very different perspectives on this question. Based on the answers to this question, there is no consensus between asphalt and concrete industries regarding the superior type of pavement where additional lanes or shoulders are to be added to an existing flexible pavement facility.

c) 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.

The level of agreement to this statement has been asked in question 11. One of the respondents believes that there is no minimum scope and large contractors would equally want to bid on small and large projects. The level of agreement of other respondents to this statement is mixed, with an average of 3.7 and standard deviation of 1.1. Question 11-1 clarifies the definition of large in question 11 by asking about the minimal project size in order to be considered large enough. Three of respondents have chosen 4 lane miles, one responded with 5 lane miles, one responded with 10 lane miles, and one has specified that it depends on the cost of project. The same respondent had indicated the minimum project cost in question 3 to be $1 million.

Therefore, this respondent believes that if a project has a minimum scope of 4 lane miles or has the cost of at least $1 million, the local availability of contractors is not a factor.

d) Flexible pavement sections tend to be significantly thicker than rigid pavements when high truck traffic is projected.

The level of agreement to this statement has been asked in question 22 which is 3.6 on average with the standard deviation of 1.0. The definition of high truck traffic has been asked in question 32. The average of responses to this question is 19-24%. In other words, the percentage of truck traffic between 19-24% is considered high truck traffic. One of the respondents has noted that high truck traffic depends on AADT. The respondents were asked again regarding the definition of high truck traffic in terms of AADT.

e) Sub grade condition must be verified prior to the design of either pavement type.

The average level of agreement to this statement is 4.2 with the standard deviation of 1.3. This factor has been asked in question 23. There is only one responder that strongly disagrees between and all the other respondents are either agree or strongly agree.

f) Rigid pavements should be placed where significant vehicle braking actions occur, such as at intersections and ramps.

The average level of agreement to this statement is 4.3 with the standard deviation of 1.0. This factor has been asked in question 24. Except one respondent that has disagreed with this statement, all the other respondents have answered with levels of agreement of 4 or 5.

g) For flexible pavement design, the divisions should be allowed to vary the minimum time to first overlay depending on their experience and conditions.

The average level of agreement to this statement is 3.9 with the standard deviation of 0.9. This factor has been asked in question 25. Except one disagreement and one neutral answer, all the respondents have answered with levels of agreement of 4 or 5. Both asphalt and concrete industries agree that the performance of flexible pavement can vary among the divisions.

h) Asphalt pavement surfaces create lower level of tire/pavement noise compared to concrete pavement.

The average level of agreement to this statement is 3.5 with the standard deviation of 1.0. This factor has been asked in question 30. Two respondents have disagreed with this statement, and considering the standard deviation of 1.0, it can be inferred that the level of noise is not a significant factor in the pavement type selection process.

One of the respondents has agreed with this statement but has noted that it is initially true but not in the long term. In other words the level of noise in flexible pavements increases as they get aged.

i) User delays need to be incorporated in LCCA for alternate pavement type bidding.

The average level of agreement to this statement is 4.0 with the standard deviation of 0.7. This factor has been asked in question 31. This question has obtained the smallest standard deviation suggesting that the respondents have consensus on this statement. Therefore user costs need to be incorporated in LCCA for alternate pavement type bidding process.

j) For asphalt; contractors are paid based on the tonnage of material delivered to the construction site while for concrete; the payments are based on the volume of pavement as per the design. This may create bias towards asphalt pavement especially when design has underestimated the required concrete volume. To facilitate a fair environment for competition, it would be better to use a single payment method for both types of pavement.

The average level of agreement to this statement is 3.7 with the standard deviation of 1.3. This factor has been asked in question 30. This statement has received one strong disagreement, one disagreement, and one not sure from the respondents. Therefore, although the average of level of agreement is more than 3.5, the level of consensus on this statement is not considered high. On the other hand, this statement has received a strong agreement from one of the division engineers and one of the industries. This means that this is a controversial issue that needs to be discussed further with all the stakeholders involved in the pavement type selection decision making process.

3.5.2 Non-Significant Factors

Based on the results of the survey analysis, constructability and utility issues are not significant in selecting projects for alternate bidding. Therefore it can be concluded that:

a) The pavement type of adjoining sections or type of previous projects along a roadway does not differentiate between different pavement types.

b) Completion time of project is not a significant factor in pavement type selection. But the respondents have agreed that user costs need to be incorporated in LCCA and completion time of projects is one of the deriving factors in user cost calculations.

c) A utility maintenance issue does not affect the pavement type selection process.

3.5.3 Further Factors Suggested by Respondents

Respondents have also suggested some other factors to be considered in selecting projects for alternate bidding:

a) Price adjustment clause that is used for asphalt pavement need to be considered when comparing flexible pavements with rigid pavements.

b) Time for plan development is a significant factor when deciding whether or not to include a project in alternate bidding because it requires two different sets of plan.

In a discussion about the answer given to the question number one, one of field division engineers brought up the point that "If both construction methods are equally, in other words I have no preference on the particular project. Then yes my answer is still 1-5%." To this division, some factors are more important than initial construction costs. Some of these factors were explained by the following examples:

> "One example would be where you are constructing a new roadway and the entire route has been for example PC paving, my preference would be to keep the roadway consistent. For example US-287 from Boise City North is being constructed of PC paving, once you hit the Colorado State line it too is PC paving. I have chosen to complete the last phase with PC paving for consistency reasons. Another example would be at an intersection where you have a lot of turning truck traffic, my preference would be to use PC paving."

3.6 Project Selection Procedure for Alternate Bidding

The significant factors determined during the questionnaire survey analysis as well as discussions and interviews with ODOT engineers, revealed that although the significant factors dictating the type of pavement have not been documented, decision makers are using almost a single set of factors throughout the state. A pavement type selection flowchart is created based on the results of the questionnaire survey analysis (Figure 3.4). The purpose of this flowchart is to determine the pavement type when the engineering factors and LCCA indicate that a pavement type is clearly outperforming. When a pavement type is not superior in terms of engineering factors and LCCA, then the alternate pavement designs are considered equivalent and suitable for alternate pavement type bidding process. The following factors are considered principal factors in pavement type selection:

- The difference between construction costs of pavement alternatives
- The size of alternate pavement project (in terms of dollar value of pavement construction)
- Whether additional lanes or shoulders are added to the existing flexible pavement

Secondary factors are as follows:

- Significant vehicle braking actions
- Heavy traffic level
- Scope of project and local availability of contractors from both industries

The alternative pavement designs for each project are determined and pavement construction cost for each pavement alternate is calculated. If the difference between pavement construction costs is more than 25%, then it means that one pavement type is significantly dominating the others. If the pavement construction costs are within 25%, then the size of project is checked. For a project to be recommended for alternate bidding the pavement construction cost should be more than $7.2 million. Alternative pavement designs that do not satisfy this criterion are checked against engineering factors such as level of traffic, existing pavement type, vehicle braking actions, local availability of contractors, soil strengths, and regional preferences to see whether a pavement type is preferred. If no pavement type is preferred in terms of engineering factors, then the pavement with lower construction cost is selected. For project with construction cost of $7.2 million and more, it should be checked further to determine whether or not the project involves construction of a new lane or shoulder on an existing flexible pavement. If this is the case then flexible pavement is preferred over rigid pavement. Otherwise, LCC for each alternative pavement is calculated and compared. The LCCs of pavement alternatives should be within 13% in order to be considered close enough for consideration in the alternate bidding process. Up to this stage, no pavement alternative is dominating in terms of principal factors and the LCC of alternative pavements are close, however the secondary factors might cause a pavement type to outperform the others. If the project includes an intersection where significant vehicle braking actions occur or the AADT of truck traffic is greater than 10,000 the rigid pavement is selected and project is not an appropriate candidate for alternate pavement type bidding. If vehicle braking actions or amount of heavy traffic is not a concern, the scope of project is checked to ensure that it is longer than a certain threshold. If the project scope is less than 4.4 lane miles and the local availability of contractors is a concern then a pavement alternate that is supported by the majority of contractors should be selected. Projects with the minimum scope of 4.4 lane miles where the local availability of contractors is not a concern would be considered appropriate projects for pavement alternate bidding.

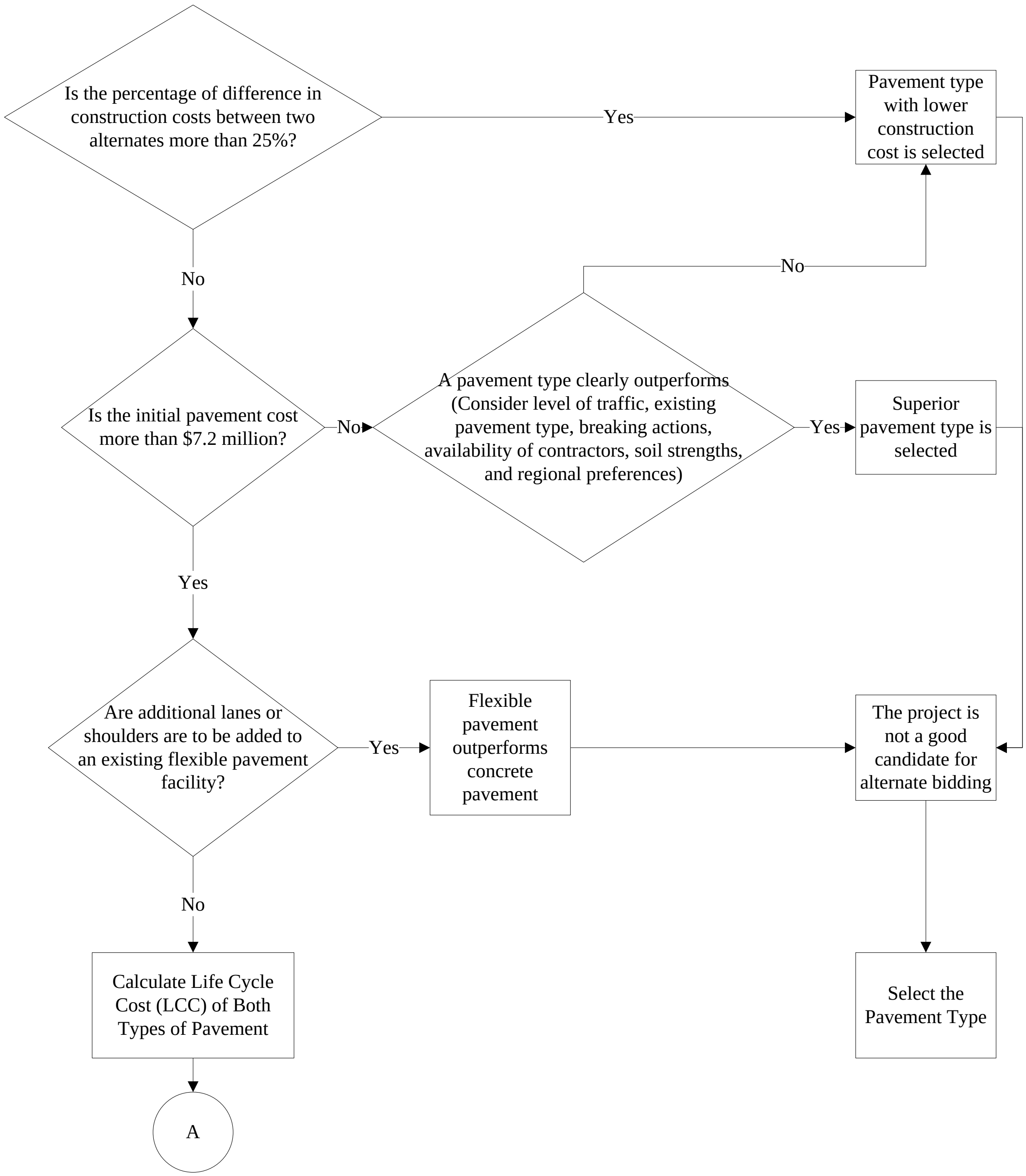


Figure 3.4 Pavement Type Selection Procedure

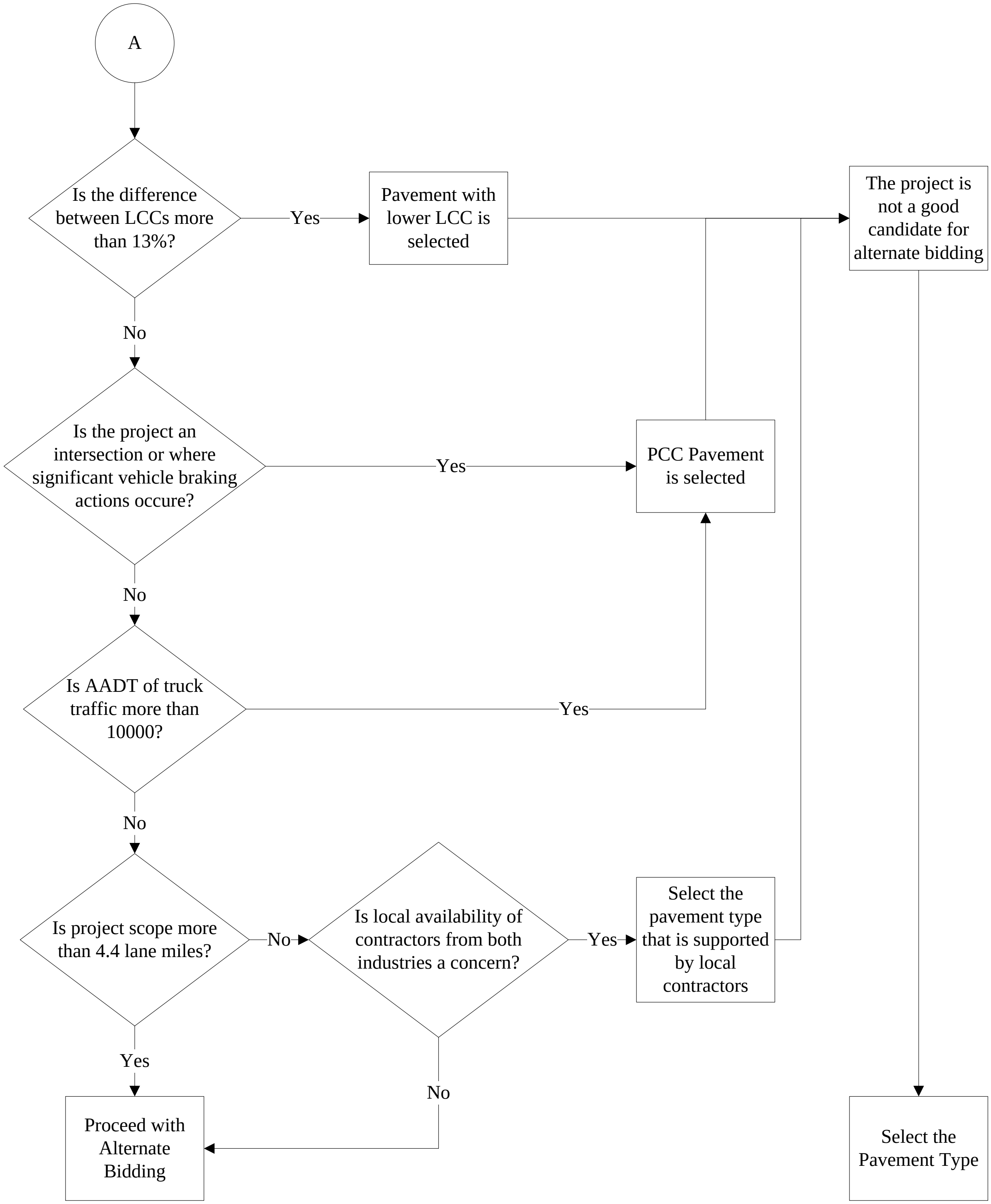


Figure 3.4 Pavement Type Selection Procedure (Cont'd)

3.7 Summary

Pavement designs must be equivalent in order to be considered appropriate candidates for alternate pavement type bidding. According to FHWA, equivalent designs perform equally, provide the same level of service, and has similar life-cycle cost. However, determining equivalent pavement designs is not an exact science but one in which the highway engineer or administrator must make a judgment on many varying factors such as traffic, soils, weather, construction, maintenance, and environment (AASHTO Guide for Design of Pavement Structures). A questionnaire survey study was performed and the significant factors affecting the pavement type selection process were identified. The significant factors were divided into principal and secondary factors based on their level of importance in decision making in ODOT. Principal factors are the factors that dictate the pavement type even if the LCCs of alternative designs are close. The secondary factors are only checked for projects that their LCCs are close enough. Based on the significant factors a flowchart was developed. If no pavement design is clearly superior in terms of principal factors, LCC, and secondary factors then the project is considered a good candidate for alternate pavement type bidding because the alternatives have equivalent designs.

Chapter 4 INTERSTATE HIGHWAY STRUCTURAL PAVEMENT HISTORY

The interstate structural history data set for Interstate 40 (in Oklahoma) is utilized in this study. This data set is used to identify the treatment patterns using the association rule mining technique. The pavement types in Interstate 40 can be categorized into four different types:

1) Flexible
2) Rigid
3) Composite
4) Others.

A breakdown of this highway based on the pavement types can be seen in Figure 4.1. The high percentage of rigid pavement sections in this highway makes it an appropriate choice for the study of alternate pavement type bidding.

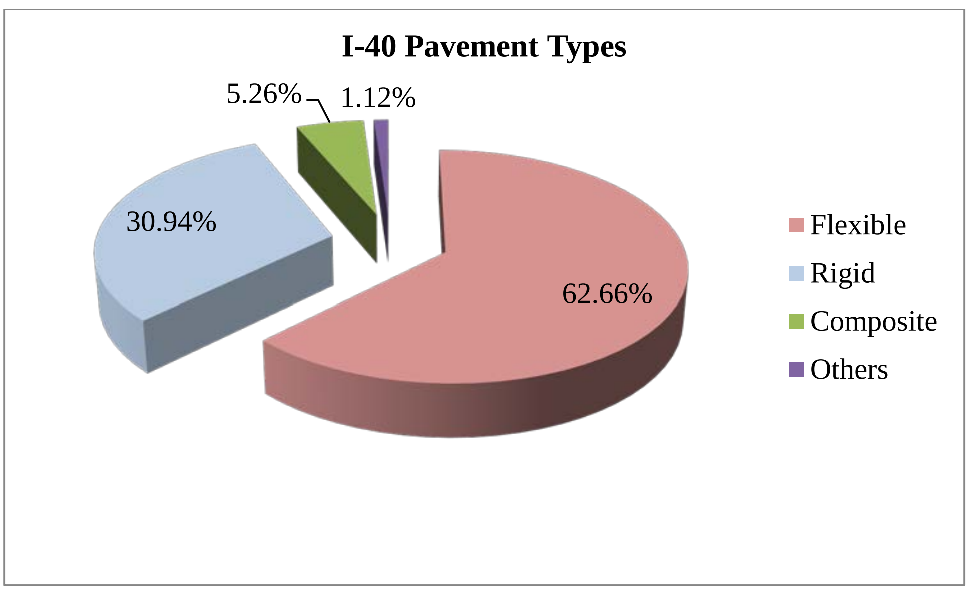


Figure 4.1 Different Pavement Types in I-40

This data set is a record of the construction and major treatment projects on the Interstate 40 in Oklahoma. Figure 4.2 shows a schematic section of the data set. The ODOT's pavement management branch checks the accuracy of this data set and updates it based on the latest construction activities on a regular basis. This report has been issued on a yearly basis since 1994. In this study the 2010 data set is used. The primary sources of project information include Planning & Research Division log cards, Bureau of Public Roads interstate strip maps, as-built drawings, and the ODOT Oracle database.

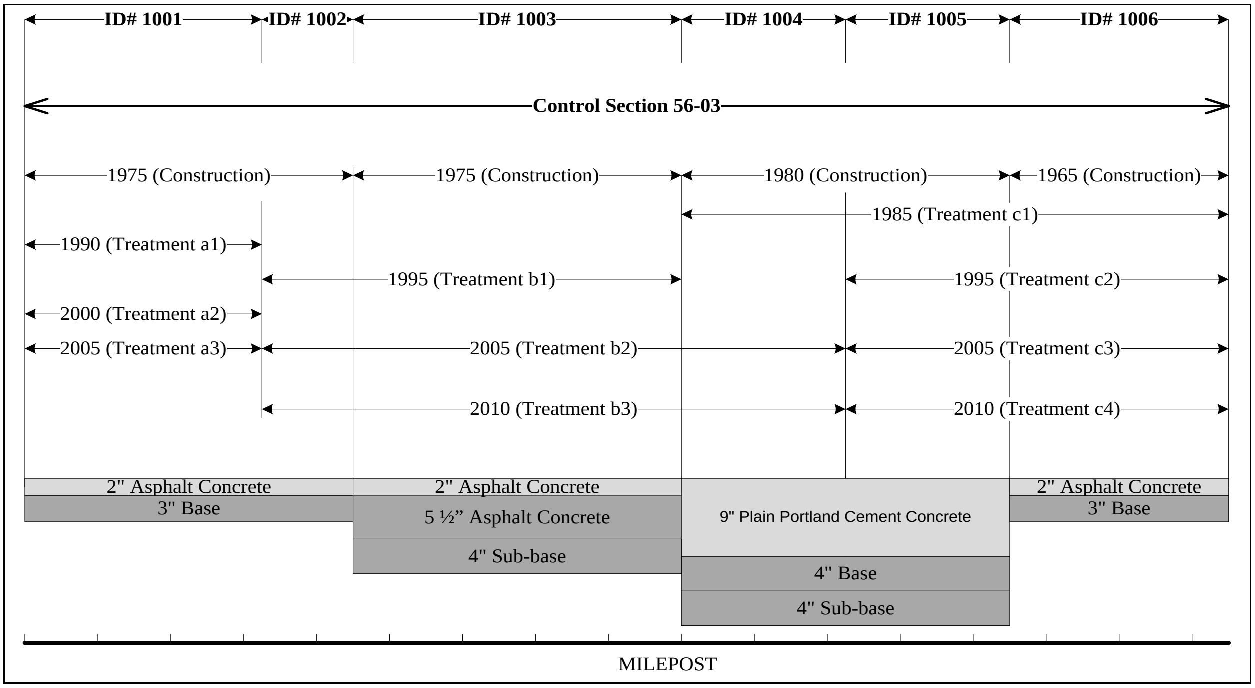


Figure 4.2 A Sample of Schematic Section of Interstate Structural History Database

4.1 Log Card

Log cards are being used to keep track of projects performed on each control section. The log card of control section 56-03 in Interstate 40 can be seen in Appendix C. These log cards are stored in the Planning and Research Division in ODOT. Since 2008, an electronic copy of these log cards is also available on the servers of ODOT. The important information on the most log cards have been transformed into spreadsheet formats and the electronic copy of them are available on the servers for future references. However, the entire log cards have been stored in the planning and research division in case the electronic copy cannot be accessed online. The data that can be found in a log card are:

- Control Section Number
- County name
- Start and end of the control section
- List of projects performed on the control section
- Project information:
    - Completion date of project
    - Project number
    - Brief explanation about the type of project, whether a project is reconstruction, overlay, flexible pavement, and rigid pavement among others.
    - Width
    - Thickness of based and surface
    - Length
    - Start point and end point

4.2 Control Section

A control section is a specific segment or roadway assigned as a permanent unit for identification and record keeping. Control sections are assigned within a county with termini normally at county lines or major highway junctions. The entire state highway inventory data have been divided into control sections. A code has been assigned to each control section which is made of three different parts. The first part is the numerical portion of the route; the second part is the county code; and the third part is the control number. Figure 4.3 shows a snapshot of the control section map of Okmulgee County. The part of interstate 40 (in blue) that passes through this county is made of only one control section with the number of 40-56-03. The small box containing control section number also shows the length of the section in miles (left side) and kilometers (right side).

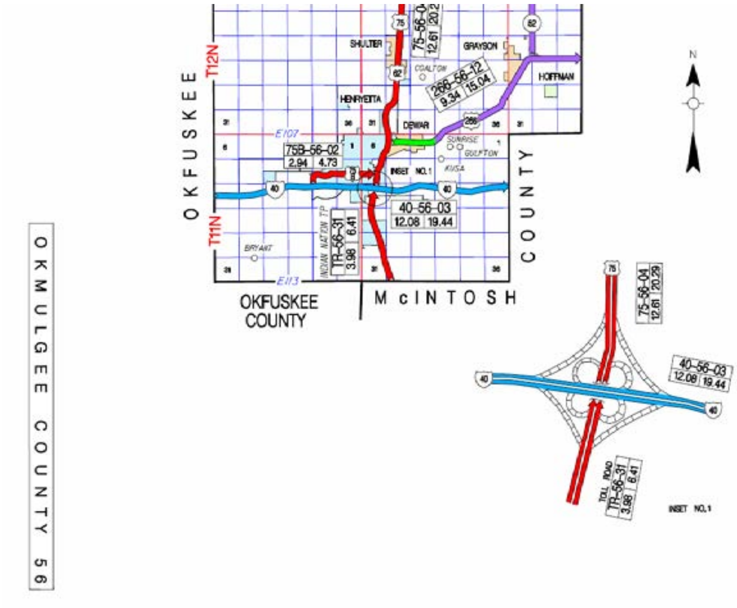


Figure 4.3 Control Section Map of Okmulgee County in Oklahoma

The portion of Interstate 40 passing through the state of Oklahoma is 330.66 miles long starting from the Texas state line and ending in Arkansas state line. It passes through 4 divisions, 13 counties and consists of 18 control sections as shown in Table 4.1.

Table 4.1 Control Sections of Interstate 40

Division	County	County Number	Control Sections
5	Beckham	5	[05-01] [05-04]
7	Caddo	8	[08-48]
4	Canadian	9	[09-05]
5	Custer	20	[20-02] [20-04]
1	Mcintosh	46	[46-07]
1	Muskogee	51	[51-15]
3	Okfuskee	54	[54-22]
4	Oklahoma	55	[55-68] [55-69]
1	Okmulgee	56	[56-03]
3	Pottawatomie	63	[63-40] [63-41]
3	Seminole	67	[67-37]
1	Sequoyah	68	[68-22] [68-23]
5	Washita	75	[75-02]

Figure 4.4 shows a snapshot of 2010 Highway Structural Pavement History for Interstate 40 control section 56-03. It illustrates all the components of the data set and identifies where the data is located. As can be seen in this figure this data set is published and maintained in visual format. It specifies time, location and scope of all pavement construction, reconstruction, and treatment projects since Interstate 40 was constructed. It includes the year that projects are opened to traffic, structural layering of the initial pavement and modifications to the initial structural layering through the time, scope of treatment activities, and project numbers for both westbound and eastbound of the Interstate 40. The locations of projects are defined by including the beginning and the end mile posts for all projects that have been performed in Interstate 40.

By looking at Figure 4.4, one can realize that the construction of Interstate 40 from mile post 233.39 to 237.01 has been finished in 1965 by project number I-40-6(39)232; the structural layering of this project is 9” Mesh Dowel P.C. Concrete, 6” Soil Asphalt, and 6” Select material; this project is part of control section number 56-03 in Okmulgee county; a portion of this section with the beginning mile post of 233.39 and ending mile post of 236.59 has undergone a maintenance joint patching project (the time of this project has been pulled out from another source which is discussed in the next section); in 2008 another P.C. Patching project has been performed on this pavement section with project number SSR-156N(148)SR.

4.3 Subsections

The planning and research division in ODOT has broken down control sections into smaller and more manageable subsections. Like the control sections, subsections have different lengths. There are various reasons that trigger the creation of subsection in a control section. A list of break reasons followed by ODOT is available in Appendix D.

Table 4.2 shows the subsections of control section 56-03 and the break reason for each subsection. Control section 56-03 is 12.08 miles and consists of 13 subsections with lengths ranging from 0.09 mile to 4.8 miles. As can be seen in this table reasons for breaking a control section into subsections can be as varied as entering new county, entering city limits, leaving city limits, junctions with other highways, and existence of test sites. These break rules are not consistent with the objective of evaluating the performance of pavement sections. The performance of a pavement section does not change as it enters a new county or a test site. In addition, the rules defined by ODOT do not capture differences in the directions for divided highways. In dividing highways south to north direction and west to east direction are considered as primary directions. Subsections are defined based on the primary directions. Therefore, different variances in directions cannot be accounted for if ODOT rules are used for dividing control sections. Therefore, finding the performance patterns in the sections that have been divided based on the reasons that are not correlated with their performance can result in performance models that are hard to interpret or not meaningful.

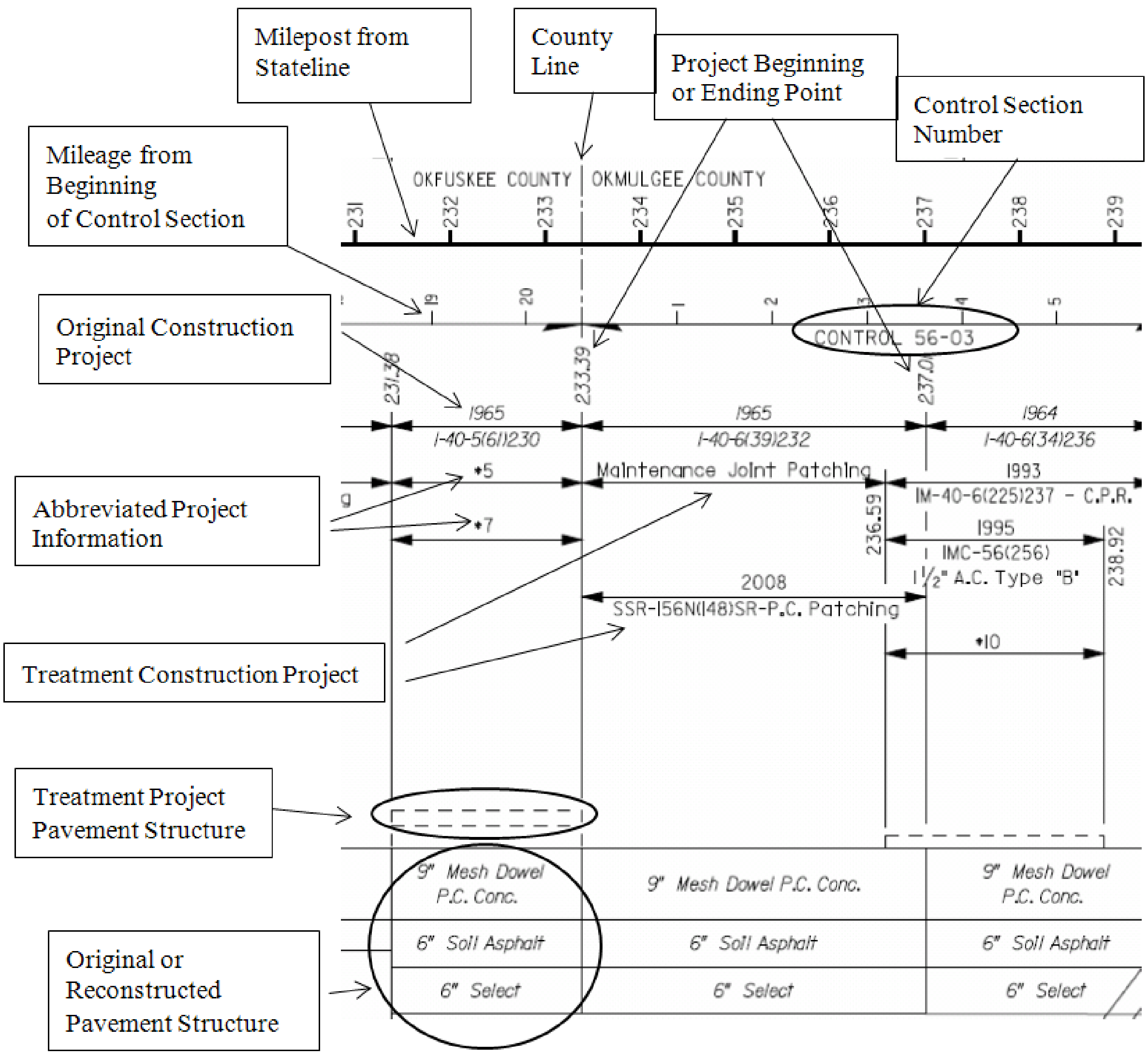


Figure 4.4 A Snapshot of Interstate Highway Structural Pavement History

4.4 Data Preparation

The data needs to be cleaned and prepared before performing the analysis. The data preparation process can be categorized into five major steps. In the first step the data is transformed from a graphical format into a spreadsheet format. Then the control sections are broken down into subsections with different break rules than what is followed by planning and research division in ODOT. In the next step, the discrepancies are corrected and missing data are pulled from other data bases available in ODOT. Then the scope of treatment activities are replaced with newly defined treatment types. In the final step, data is transformed into a transactional format in order to be ready for the data mining purposes.

Table 4.2 Break Reasons of Control Section 56-03

Control Section	Subsection Number	Beginning Mile	Break Reason	Ending Mile
56-03	5603 00000000	0	Begin control section at County or State line	3.02
56-03	5603 00000302	3.02	Enter urban area boundary	3.2
56-03	5603 00000320	3.2	Surface width or type change	3.52
56-03	5603 00000352	3.52	HPMS break	3.93
56-03	5603 00000393	3.93	State highway junction	4.02
56-03	5603 00000402	4.02	Enter municipal limits	4.2
56-03	5603 00000420	4.2	Leave municipal limits	5.65
56-03	5603 00000565	5.65	Enter municipal limits	6.04
56-03	5603 00000604	6.04	State highway junction	6.6
56-03	5603 00000660	6.6	HPMS break	6.75
56-03	5603 00000675	6.75	HPMS break	7.03
56-03	5603 00000703	7.03	Leave urban area boundary	7.28
56-03	5603 00000728	7.28	HPMS break	12.08

4.4.1 Transforming Data Set

According to the pavement management branch of ODOT, the graphical format of the Interstate Highway Structural Pavement History data set is the most updated format. Therefore the research team decided to use the data set in the graphical format and convert it into a spread sheet format. This required the research team to spend a significant amount of time to enter the data into a spreadsheet from a hard copy of the data set. Table 4.3 shows a schematic of the spreadsheet created for data transformation.

Table 4.3 Schematic of Spreadsheet Created to Transform Data

Section ID	**Pavement Section Information**			**1st Treatment Project**		**2nd Treatment Project**		**3rd Treatment Project**	
	Original Construction Project	Location	Structural Layering	Year	Scope	Year	Scope	Year	Scope
1001									
1002									
1003									
1004									
1005									
1006									
1007									

4.4.2 Breaking Control Sections

The control sections are several miles long and usually consist of pavement sections with different structural layering, construction time, and treatment histories. Figure 4.5 shows control section 54-22 on Interstate 40 in Okfuskee County with beginning milepost of 212.80 and ending mile post of 233.39. This control section consists of three different pavement types:

1) asphalt concrete
2) continuous reinforced concrete pavement
3) mesh dowel Portland cement concrete pavement.

In addition, the pavement section with beginning mile post of 219.71 and ending mile post of 226.56 has undergone three different treatment strategies since its construction in 1965. In order to study the performance of pavement sections, control sections need to be broken down into smaller sections with homogenous structural layering, construction year, and treatment history. As was mentioned earlier, subsections defined by ODOT are not recommended to be used in this study because their break rules are not consistent with the criteria that affect the performance of pavement sections. The difference in treatment history between westbound and eastbound can also be seen in Figure 4.5 from milepost 223.21 to 224.31. Therefore, control section 54-22 is divided into 6 subsections in the eastbound and 7 subsections in the westbound. These subsections are illustrated in Table 4.4. In the restructured data set, each control section is divided into smaller sections based on the following factors:

- Original pavement type
- Original pavement construction year
- Treatment history

Table 4.4 Subsections of Control Section 54-22 in the Eastbound and Westbound Directions

Subsection	Direction	Beginning Mile Post	Ending Mile Post	Length (miles)
1	Eastbound	212.8	219.71	6.91
2	Eastbound	219.71	220.59	0.88
3	Eastbound	220.59	223.21	2.62
4	Eastbound	223.21	226.56	3.35
5	Eastbound	226.56	231.38	4.82
6	Eastbound	231.38	233.39	2.01
1	Westbound	212.8	219.71	6.91
2	Westbound	219.71	220.59	0.88
3	Westbound	220.59	223.21	2.62
4	Westbound	223.21	224.31	1.1
5	Westbound	224.31	226.56	2.25
6	Westbound	226.56	231.38	4.82
7	Westbound	231.38	233.39	2.01

4.4.3 Cleaning Data Set

ODOT has started collecting and publishing the Interstate Highway Structural Pavement History data set since 1993. This is despite the fact that the last section of Interstate 40 has been built in 1975. Therefore, the main challenge in developing this data set has been collecting the information of projects that had been constructed years ago. In addition, the amount of data stored in the log cards is so limited and in some cases illegible. The main data cleaning activity was focused on the missing data. Some examples of missing data and the way they have been handled are explained below.

In some cases, the scope of project is not well defined. It required the research team to study the site plan or log card of each project individually to obtain the scope information. For instance, for some projects the thicknesses of overlays are not available in the data set. Or the project scope is not detailed enough to fall under a specific treatment type. For instance, the word resurfacing is not giving enough information regarding the type of material used for treatment, whether or not milling has taken place or the thickness of overlay.

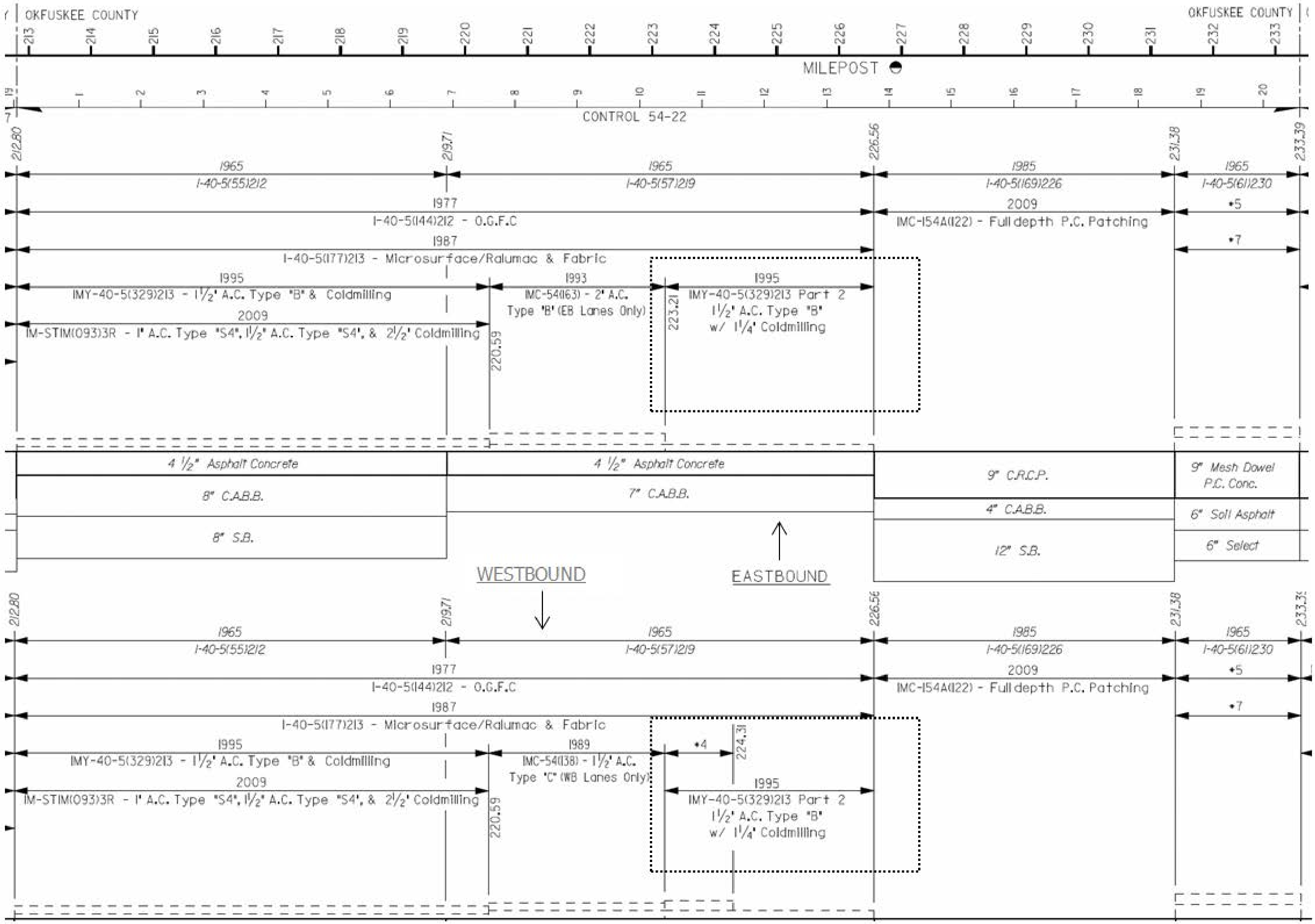
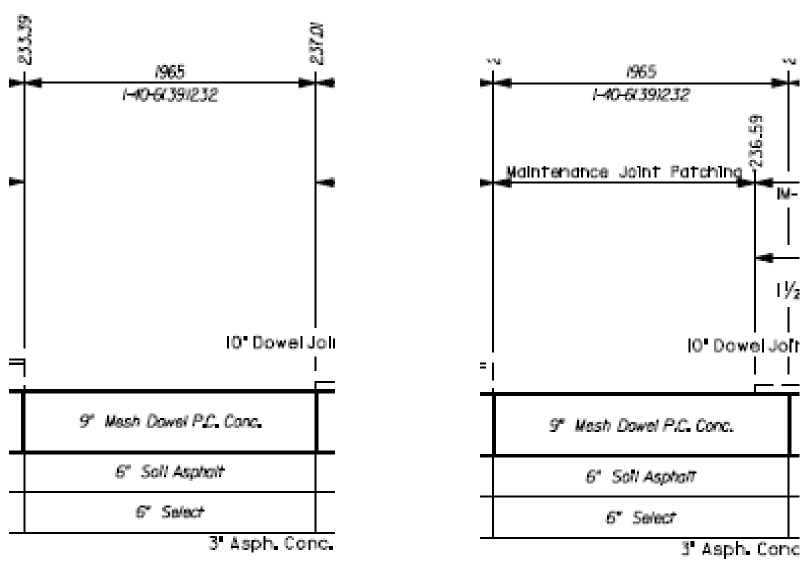


Figure 4.5 Structural Pavement History for Control Section 54-22 (Eastbound and Westbound)

In another case the project number and construction year were missing for a treatment project. In a portion of control section 56-03 in Interstate 40 with the beginning mile post of 233.39 and the ending mile post of 236.59 the construction year and project number are missing for the first treatment that has been applied on the pavement. However, by looking into the data set of previous years it was found out that this treatment activity has been added to the reports since 2003. This helped the research team to estimate the construction year of this treatment activity without having the project number and looking into the project plan. Figure 4.6 shows how a missing construction year has been determined.

4.4.4 Defining Pavement Treatment Types

The ODOT planning and research division has categorized pavement treatment types based on traffic level, type of material, type of activity, thickness of material, and the existing pavement among others. The data that the research team have focused on this research belongs to Interstate 40 and traffic level for all the pavement sections in this highway is considered high traffic level. The pavement treatment types for high traffic level defined by ODOT together with their definitions can be seen in Table 4.5.



2002 Data 2003 Data

Figure 4.6 A Strategy to Handle Missing Data

Table 4.5 Treatment Types Defined by ODOT

Name	Treatment Activity
BondedOL_HV	Bonded Overlay on JPCP pavement (include DBR w/o grind) (high volume)
DBR_Grind_HV	Dowel-Bar Retrofit and Grind of JPCP pavement (high volume)
Grind_HV	Grinding of concrete pavement (high volume)
JtRepair_HV	Joint repair project (high volume)
JtSeal_HV	Joint Sealing project (high volume)
MicroSurf_HV	Surface texture of asphalt pavement (high volume)
MillMedOL_HV	Mill & 2" SMA & 1.25" PFC Overlay on AC pavement (high volume)
MillThkOL_HV	Mill & 7" Overlay on AC pavement (high volume)
MillThnOL_HV	Mill & 2.25-inch Overlay (high volume)
ReplaceToAC_HV	Replacing AC pavement with AC (high volume)
ReplaceToCRCP_HV	Replacing existing PC pavement with CRCP (high volume)
ReplaceToDJCP_HV	Replacing any existing pavement with DJCP (high volume)
ReprCRCP	CRCP repair project
SlabRepr_HV	Slab repair project (high volume)
ThnOL_HV	2.25-incb Overlay of asphalt pavement (high volume)
UnBonded_HV	Unbonded overlay
Whitetopping_HV	Whitetopping

After investigating the data set, the research team found out that overlay thicknesses are ranging from 0.75 to 9 inches. Figure 4.7 shows a histogram of AC overlay thicknesses. According to ODOT definitions, thin, medium and thick overlays are called to overlays with thicknesses of 2.25, 3.25 or 7 inches accordingly. After discussing this issue with ODOT planning and research division, construction division, and roadway design division, the research team decided to create intervals to categorize overlays into thin, medium, and thick overlays.

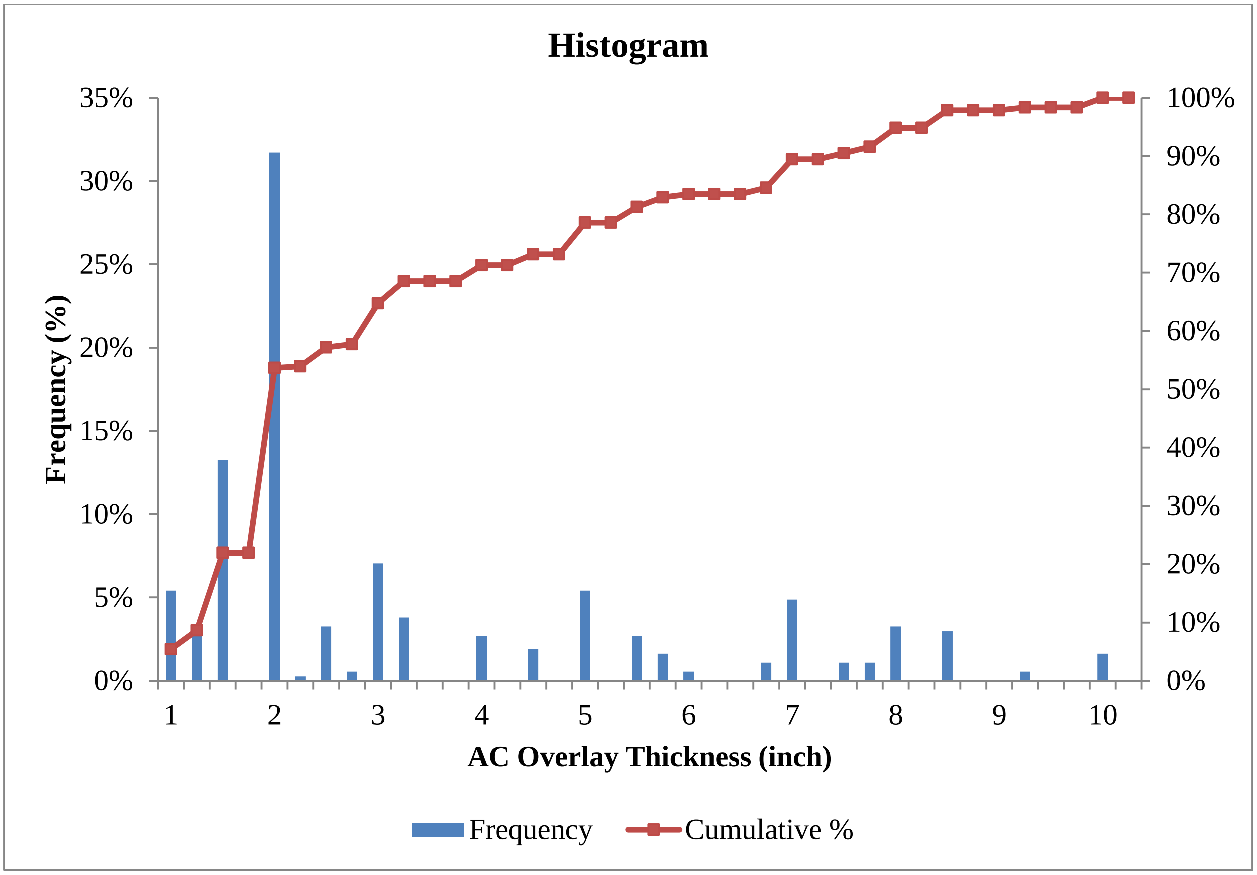


Figure 4.7 Frequency Distribution of AC Overlay Thicknesses

All the AC overlays with the thicknesses of less than 3 inches are categorized as thin overlays. Treatment activities with AC overlay thicknesses of 3 inches or more up to 6 inches are considered as medium overlays. All the AC overlays with the thicknesses of 6 inches and more up to 10 inches are categorized as thick overlays. Table 4.6 shows the rules utilized to categorize AC overlays. The frequencies of thin, medium, and thick overlays can be seen after grouping them based on the rules in Figure 4.8.

Table 4.6 Rules for Categorizing AC Overlays Based on Thicknesses

AC Overlay Type	Rule
Thin Overlay	Thickness < 3 inches
Medium Overlay	3 inches ≤ Thickness < 6 inches
Thick Overlay	6 inches ≤ Thickness ≤ 10 inches

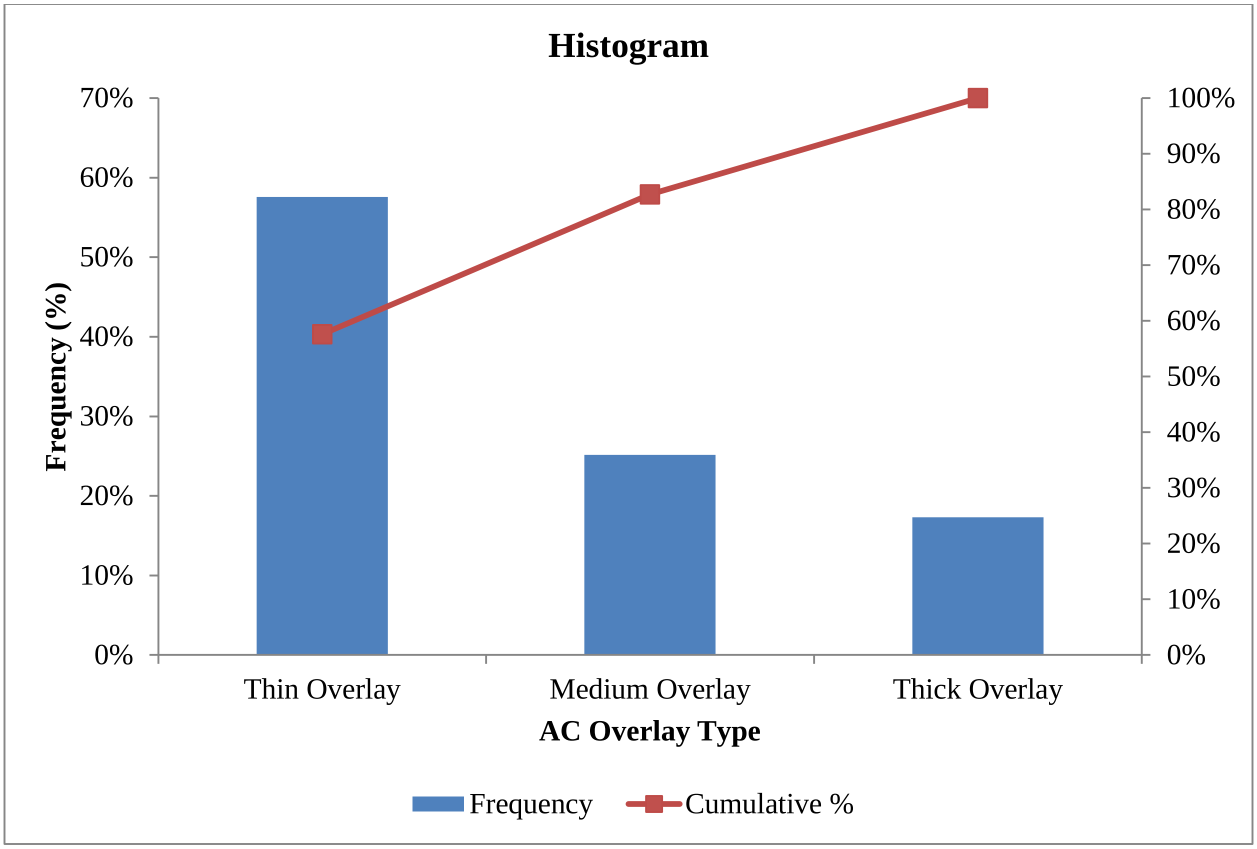


Figure 4.8 Frequency Distribution of AC Overlay Types

The treatment activities on Interstate 40 are more diverse than the treatment types defined by ODOT. In many cases, AC overlays are not combined with milling, or they are associated with Fabric, OGFC, both Fabric and OGFC, or Chip Seal. Therefore the research team decided to define more treatment types in order to capture the patterns in treatment activities more accurately. These variances are captured by the following rules:

a) If an AC overlay is not associated with Fabric, OGFC, or Chip Seal then number 1 is placed on the right hand side of treatment name.
b) If an AC overlay is associated with Fabric, number 2 is placed on the right hand side of treatment name.
c) If an AC overlay is associated with OGFC, number 3 is placed on the right hand side of treatment name.
d) If an AC Overlay is associated with both Fabric and OGFC, number 4 is placed on the right hand side of treatment name.

e) If an AC overlay is associated with Chip Seal, number 5 is placed at the right hand side of treatment name.

The final treatment types defined to categorize treatment activities are illustrated in Table 4.7. The combinations created in AC overlays after considering Fabric, OGFC, and Chip Seal are captured by adding above mentioned numbers to the treatment names.

4.4.5 Restructuring Data Set

This data set should be restructured before the association rules mining analysis is applied. The appropriate data set structure is available in Table 4.8. In this data set, each row represents a treatment activity on a subsection. A unique ID is allocated to each subsection. The first column shows the ID allocated to each subsection, the second column shows the type of treatment activity, the third column illustrates the sequence, and the fourth column shows the construction year of each treatment activity. The data for Interstate 40 has been collected for both westbound and eastbound directions. For some sections, the treatment activities or pavement structural layering for directions are not identical. Therefore, westbound and eastbound sections have been defined as separate pavement sections in the data set. As mentioned earlier, the control section 54-22 is divided into 13 homogeneous sections in terms of original pavement type, construction year, and treatment history.

The data set is restructured for the entire length of Interstate 40 in Oklahoma. This data set contains 667 rows for a total of 218 subsections where each row represents a treatment activity. As can be seen in Table 4.8, each subsection can have multiple rows in the data set, each row representing one of the treatment activities that has occurred on the section.

Table 4.7 Pavement Treatment Types in Interstate 40

Name	Treatment Activity
OGFC	Open Graded Friction Course
Microsurface	Surface texture of asphalt pavement
Microsurface_Fabric	Surface texture of asphalt pavement with fabric
PC_Patch	Selective PC Patching
Full_PC_Patch	Full depth PC patching
Patch_Level	Patching and type E leveling course
micro_Fabric	Microsurface/Ralumac and Fabric
Level_OGFC	AC leveling course with OGFC
Reconstrct	Reconstruction
BondedOL	Bonded Overlay on JPCP pavement (include DBR w/o grind)
Joint_Rehab	Joint repair project
DBR_Grind	Dowel-Bar Retrofit and Grind of JPCP pavement
Grind	Grinding of concrete pavement
JtSeal	Joint Sealing project
Grind_Seal	Diamond grind and Joint Seal
Chip_Seal	Nova Chip
Grind_Seal_Repair	Diamond grind, joint seal, and slab repair project
Mill_Thin_OL	Mill & AC Overlay of less than 3" on AC pavement
Mill_Med_OL	Mill & AC Overlay of 3" to 6" on AC pavement
Mill_Thick_OL	Mill & AC Overlay of 6" to 10" on AC pavement
Thin_OL	AC Overlay of less than 3" on AC pavement
Med_OL	AC Overlay of 3" to 6" on AC pavement
Thick_OL	AC Overlay of 6" to 10" on AC pavement
HIP_Chip	Hot in place recycling with Nova Chip
ReplaceToAC	Replacing AC pavement with AC
ReplaceToCRCP	Replacing existing PC pavement with CRCP
ReplaceToDJCP	Replacing any existing pavement with DJCP
ReprCRCP	CRCP repair project
SlabRepr	Slab repair project
Unbonded_OL	Unbonded overlay
Whitetopping	Whitetopping

Table 4.8 Restructured Data Set for Control Section 54-22

Subsection ID	Pavement Type	Original Construction Year	Treatment Year	Treatment Type	Sequence
1159	AC	1965	1977	OGFC	1
	AC	1965	1987	Microsurface_Fabric	2
	AC	1965	1995	Mill_Thin_OL1	3
	AC	1965	2009	Mill_Thin_OL1	4
1160	AC	1965	1977	OGFC	1
	AC	1965	1987	Microsurface_Fabric	2
	AC	1965	1995	Mill_Thin_OL1	3
	AC	1965	2009	Mill_Thin_OL1	4
1161	AC	1965	1977	OGFC	1
	AC	1965	1987	Microsurface_Fabric	2
	AC	1965	1995	Mill_Thin_OL1	3
	AC	1965	2009	Mill_Thin_OL1	4
1162	AC	1965	1977	OGFC	1
	AC	1965	1987	Microsurface_Fabric	2
	AC	1965	1995	Mill_Thin_OL1	3
	AC	1965	2009	Mill_Thin_OL1	4
1163	AC	1965	1977	OGFC	1
	AC	1965	1987	Microsurface_Fabric	2
	AC	1965	1989	Thin_OL1	3
1164	AC	1965	1977	OGFC	1
	AC	1965	1987	Microsurface_Fabric	2
	AC	1965	1989	Thin_OL1	3
1165	AC	1965	1977	OGFC	1
	AC	1965	1987	Microsurface_Fabric	2
	AC	1965	1993	Thin_OL1	3
	AC	1965	1995	Mill_Thin_OL1	4
1166	AC	1965	1977	OGFC	1
	AC	1965	1987	Microsurface_Fabric	2
	AC	1965	1995	Mill_Thin_OL1	3
1167	AC	1965	1977	OGFC	1
	AC	1965	1987	Microsurface_Fabric	2
	AC	1965	1995	Mill_Thin_OL1	3
1168	CRCP	1985	2009	Full_PC_Patch	1
1169	CRCP	1985	2009	Full_PC_Patch	1
1170	DJCP	1965	1991	Med_OL3	1
	DJCP	1965	2005	Mill_Thin_OL1	2
1171	DJCP	1965	1991	Med_OL3	1
	DJCP	1965	2005	Mill_Thin_OL1	2

4.5 Summary

In this study the five steps of data preparation activities were discussed. The Interstate Highway Structural Pavement History data set is updated for all the interstate highways of Oklahoma by the ODOT planning and research division. The Interstate 40 was selected by the research team for this study for three reasons: 1) High percentage of rigid pavement sections compared to other state highways, 2) One of the major interstate highways passing through the whole length of the state of Oklahoma, 2) Divided highway where data is collected for both eastbound and westbound providing more data points for the analysis. The data preparation approach adopted in this study is unique. Although this data set has been collected and published since 1994, the amount of information or knowledge extracted from it is very limited or unknown.

The Interstate Highway Structural Pavement History data set is prepared and published by ODOT planning and research division on a yearly basis; however the research team spent a significant amount of time and effort to create a data set which is appropriate for recognizing pavement performance patterns. The State Highway Agencies are required to update the FHWA regarding the structural pavement history of their interstate highways on a yearly basis. Therefore, these five steps of data preparation can also be followed by other highway agencies to convert their data into a format which is ready to be evaluated for existence of patterns in treatment activities.

The idea behind the data preparation in this chapter is to divide the section into homogenous sections where each subsection has the same original construction year, original pavement type and treatment history. This approach minimizes the amount of noise available in the data and provides a base where pavements from the same family can be compared together in terms of their performance and treatment history.

Chapter 5 DETERMINISTIC LIFE-CYCLE COST ANALYSIS

5.1 Introduction

One of the factors that need to be evaluated before including projects for alternate bidding is life-cycle cost of each pavement design. According to FHWA definition, alternative pavement designs must have similar life-cycle costs in order to be eligible for alternate pavement type bidding. Although the principals of LCCA are fairly uniform, the application of LCCA in design varies considerably among highway agencies. Different policies and priorities in different highway agencies have resulted in including different cost components in performing LCCA. In September 1998, the FHWA published an Interim Technical Bulletin in life-cycle cost analysis in pavement design. This technical bulletin presents technical guidance and recommendations on good/best practices in conducting LCCA in pavement design. It starts with discussions regarding the principals of LCCA and input parameters. It also discusses the variability and uncertainties inherent with input parameters and suggests sensitivity analysis and Monte Carlo simulation analysis. There are two approaches in performing LCCA: 1) Deterministic Approach and 2) Risk Analysis Approach.

A deterministic Approach to LCCA does not consider variability associated with the input parameters which is the main disadvantage of this approach. However, the deterministic approach is straightforward and requires a smaller amount of input parameters, which makes it more practical and easy to adopt. In the risk analysis approach, the input parameters are a range of values with different probabilities of occurrence. Therefore, unlike the deterministic approach the LCCA result is a range of outcomes as well as the likelihood of occurrence. The main disadvantage of this approach is that the true frequency distribution of input parameters is unknown in most highway agencies. This adds to the complexities of the risk analysis approach making it less popular among state highway agencies.

5.2 Deterministic LCCA

In the deterministic LCCA, all the input variables in the analysis are assigned fixed, discrete value. Based on the historical evidence or professional judgment, a value is determined as most likely and used in the deterministic LCCA. The input values are used to compute a single life-cycle cost estimate for each alternative. This approach is straightforward and is traditionally used in many state DOTs. A sensitivity analysis can be done to test input assumptions by varying one input, holding other inputs constant. When enough data is not available to capture the uncertainties in the input variables, the deterministic LCCA combined with sensitivity analysis provides state DOTs with a reasonable approach to compare alternative designs. In order to determine input assumptions in the deterministic LCCA, a combination of historical treatment data and professional judgment is utilized.

5.2.1 Develop Equivalent Pavement Designs

For a project that both asphalt and concrete pavements are feasible, there are two alternatives that need to be compared by LCCA. Therefore the two alternative pavement design strategies would be equivalent asphalt and concrete pavement designs where there is not any technical advantage in using one design over the other design. The project selection procedure for alternate bidding can be used to make sure that two pavement designs are equivalent.

5.2.2 Analysis Period

Analysis period is the time horizon over which future costs are evaluated. It should be sufficiently long to reflect long-term cost differences associated with reasonable design strategies. The FHWA recommends that the analysis period should be long enough to incorporate at least one rehabilitation activity and it should generally always be longer than the pavement design period. According to the FHWA's Final LCCA Policy statement in September 1996, an analysis period of at least 35 years should be considered for all pavement projects, including new or total reconstruction, restoration, and resurfacing projects [17] . Slightly shorter periods are also appropriate if it could simplify salvage value computations. For example, if all the alternative strategies would reach terminal serviceability at year 32, then a 32-year analysis would be quite appropriate.

Based on the survey questionnaire filled out by Study Advisory Group members as well as ODOT resident engineers, the following results were obtained based on the average of responses to questions 21 and 35:

- Answer to Question 21: Alternate pavement designs need to be designed for the service performance of 30 years.
- Answer to Question 35: The analysis period for Life Cycle Cost Analysis (LCCA) in order to reflect long-term cost differences associated with pavement alternate designs should be 37 years.

On the other hand, the analysis of historical pavement treatment data set reveals that asphalt pavement sections are treated with cold milling and medium overlays at year 33 and PCC pavement sections are typically treated with unbonded overlay at year 34. This indicates that asphalt and concrete pavements reach to their final serviceability at year 33 and 34 respectively. Therefore, an analysis period of 33 years can simplify salvage value computations and thus can be selected as the analysis period for LCC comparison of asphalt and concrete pavements during alternate bidding process. By this assumption, the PCC pavement sections have one year serviceability left at the end of year 33 which needs to be incorporated in the LCCA.

5.2.3 Performance Periods and Activity Timing

Typically, each design alternative will have an expected periodic maintenance treatments and rehabilitation activities. According to FHWA Interim Technical Bulletin regarding LCCA in Pavement Designs (FHWA 1998), depending on the initial pavement design, a variety of rehabilitation strategies need to be employed to keep the highway facilities in functional condition. The historical pavement treatment information for Interstate 40 is used to determine these rehabilitation strategies. The activity timings are determined by taking the average number of years from the original pavement construction to the time that the treatment is applied. These values are calculated and shown in Table 5.1. The activity timings are calculated separately for asphalt and concrete pavements. Asphalt pavement sections are reconstructed at year 33 and concrete pavement sections are reconstructed at year 34. Thus, asphalt pavement sections are treated two times at years 12 and 28 and concrete pavements are treated once at year 28 before they reach the end of their serviceability lives.

Table 5.1 Deterministic Timing of AC and PCC Pavement Sections

	Time (Years) after Original Construction		
	1st Treatment	2nd Treatment	3rd Treatment
AC	12	28	33
PCC	28	34	

5.2.4 Rehabilitation Activities

The historical treatment activities applied on asphalt and concrete pavements in Interstate 40 were used to determine the rehabilitation activities. The frequency of treatment activities applied on asphalt pavements as the first and the second treatment can be seen in Figure 5.1 and Figure 5.2. As can be seen in Figure 5.1, thin asphalt overlay and OGFC are the most likely treatment types that might occur as the first treatment.

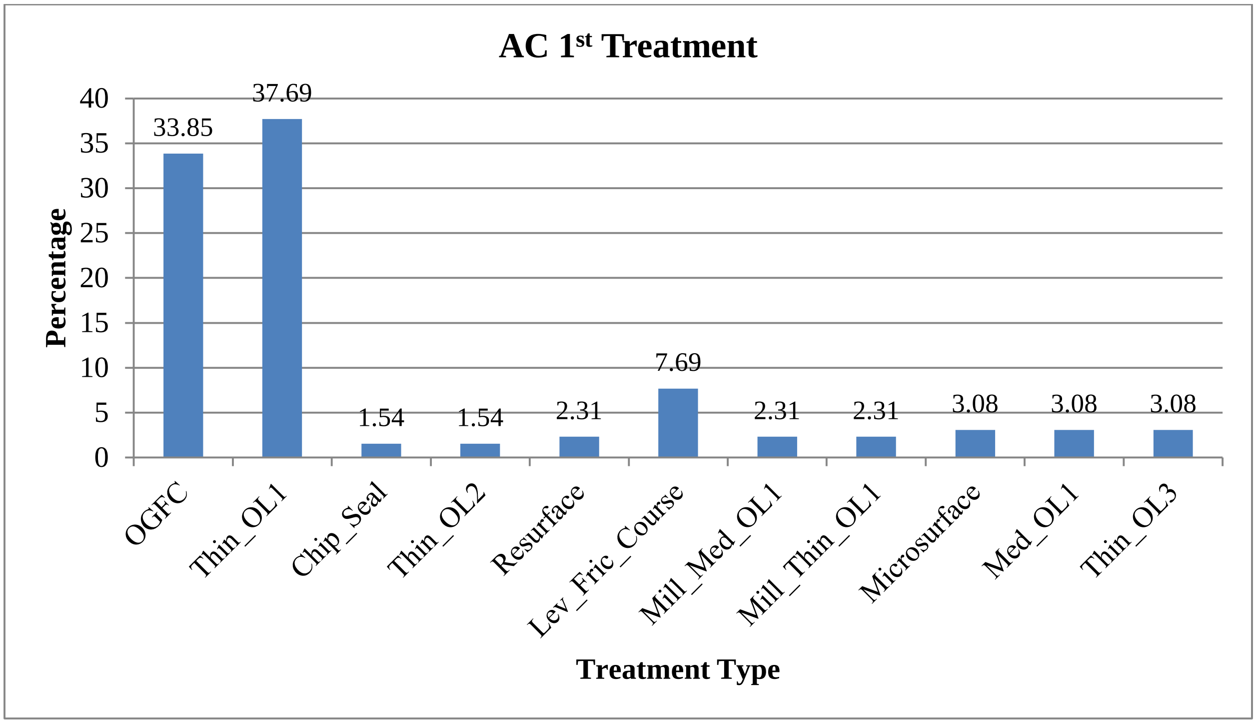


Figure 5.1 Frequency of 1st Treatment Activities on Asphalt Pavements

Figure 5.2 reveals that thin asphalt overlay, cold milling and medium asphalt overlay with OGFC and Fabric, or asphalt leveling course with OGFC are treatment activities that are most likely to occur as the second treatment. The frequency distribution of concrete pavements is shown in Figure 5.3. As can be seen in this figure, CPR is the most likely treatment strategy as the first treatment in concrete pavements. This treatment activity consists of partial slab replacement, joint rehabilitation, full-depth patching, sawing, and diamond grinding.

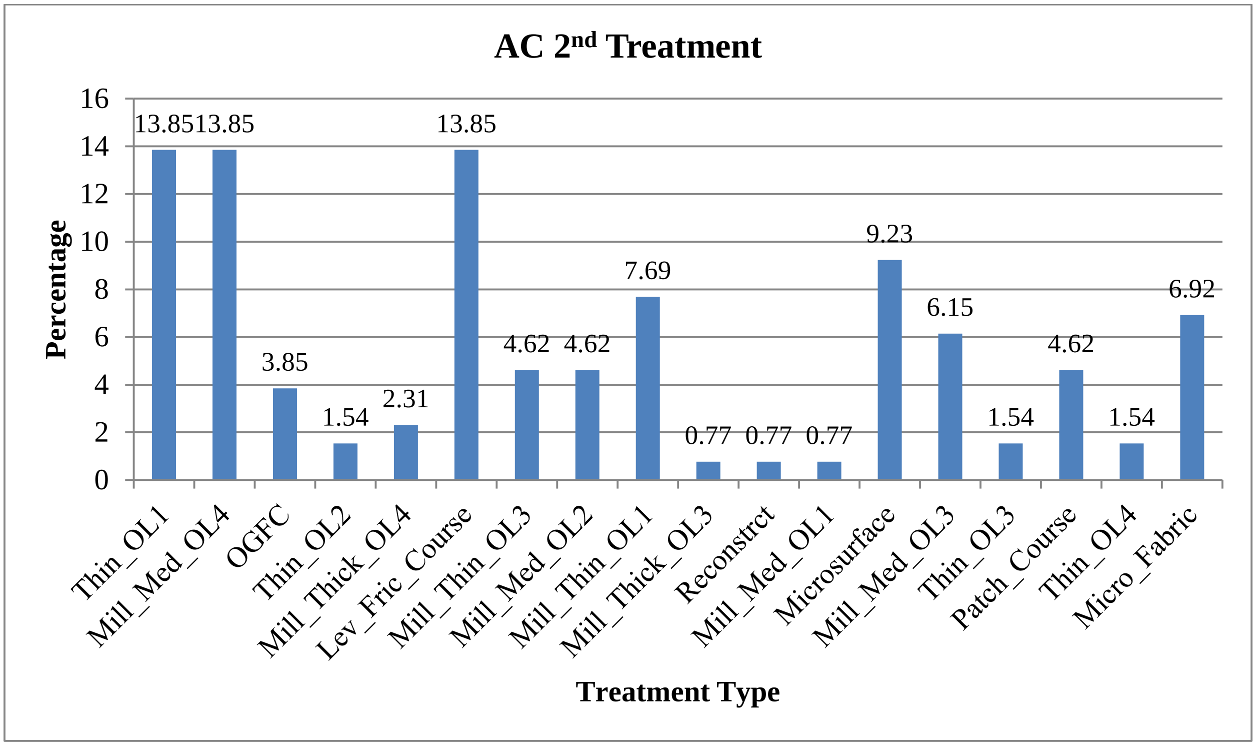


Figure 5.2 Frequency of 2nd Treatment Activities on Asphalt Pavements

The final deterministic LCC model is shown in Table 5.2. The thicknesses of coldmilling and AC overlays in this table are the averages of those values in the historical data set.

5.2.5 Estimate Rehabilitation Costs

Rehabilitation costs can be estimated by determining construction quantities and unit prices. Construction quantities are directly related to the initial design and subsequent rehabilitation strategies as shown in Table 5.2. Unit prices can be determined from ODOT historical data on previously bid jobs of comparable scale. Based on FHWA recommendations, LCCA need only consider differential cots between alternatives. Costs common to all alternatives will not change the outcome of LCCA and cancel out. However, the associated administrative, mobilization, and construction service costs are included in the LCCA. To estimate the rehabilitation costs, the following sources in ODOT are used:

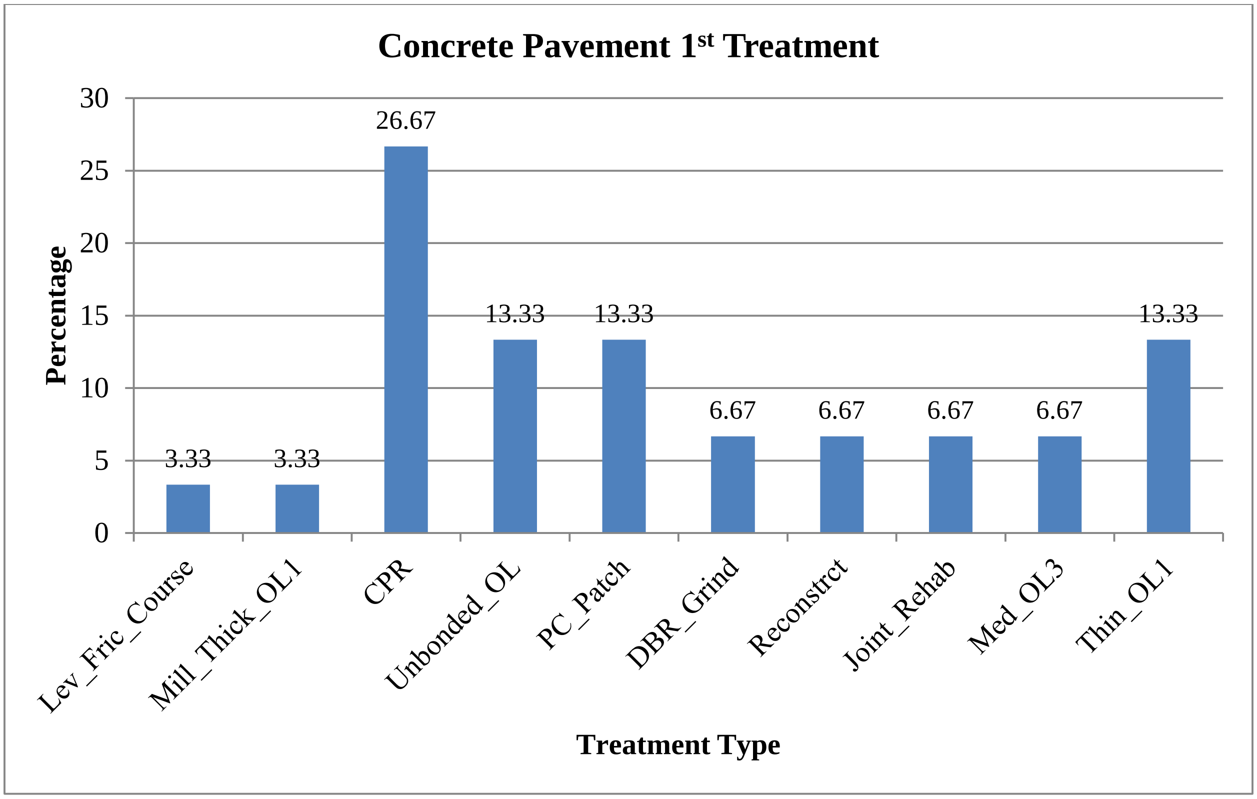


Figure 5.3 Frequency of 1st Treatment Activities on Concrete Pavements

Table 5.2 Deterministic LCC Model for Asphalt and Concrete Pavements

	Years from pavement original construction				
Pavement Type	**12**	**23**	**28**	**33**	**34**
Asphalt	1.85" AC Overlay (50%) or OGFC (50%)	2.58" Coldmilling + 4.16" AC Overlay + OGFC + Fabric		End of asphalt pavement serviceability	-
PCC	-	-	CPR	-	End of concrete pavement serviceability

- Cost estimations per square yard for different treatments, developed by Planning & Research Division. The Pavement Management Branch in Planning & Research Division utilizes these estimates to determine the funding levels needed to preserve or improve the condition of the state's highway routes.
- Weighted average item price report by item, region, and quarter which include a price history for selected items. The Construction Division utilizes this unit price history to estimate the costs of projects before letting process.

The Pavement Management Branch has estimated the treatment costs for low volume (less than 2,000 average annual daily traffic), moderate volume (2,000-10,000 average annual daily traffic) and high volume (over 10,000 average annual daily traffic). The traffic in interstate 40 is more than 10,000 average annual daily traffic and thus can be categorized as high volume. The estimated unit prices for high volume traffic can be seen in Table 5.3.

Table 5.3 Pavement Treatment Price Estimations for High Traffic

Treatment Activity	**Price ($/SY)**
Calculate Cost for Bonded Overlay on JPCP pavement (include DBR w/o grind)	50.00
Cost for Dowel-Bar Retrofit and Grind of JPCP pavement	14.20
Calculate Cost for grinding of concrete pavement	7.10
Cost for a joint repair project	7.10
Cost for Joint Sealing project	2.41
Cost for surface tx of asphalt pavement	8.52
Cost for a Mill & 2" SMA & 1.25" PFC Overlay on AC pavement	21.31
Cost for Mill & 7" Overlay on AC pavement	56.82
Cost for Mill & 5" Overlay on AC pavement	24.86
Cost for Mill & 2.25-inch Overlay	13.66
Cost for PFC on asphalt pavement	6.39
Cost for replacing AC pavement with AC	142.05
Cost for replacing existing PC pavement with CRCP	198.86
Cost for replacing any existing pavement with DJCP	170.45
Cost for a CRCP repair project	9.23
Cost for a slab repair project	9.23
Cost for 2.25-incb Overlay of asphalt pavement	18.47
Cost for Unbonded overlay	142.05
Cost for Whitetopping	113.64

5.2.6 Discount Rate

The LCCA can be performed using either real or nominal discount rates. Real discount rate reflects the true time value of money with no inflation premium and should be used with non-inflated dollar cost estimates of future investments. Nominal discount rates include an inflation component and should only be used in conjunction with inflated future dollar cost estimates of future investments. The result of LCCA can significantly be influenced by discount rates. Therefore, selecting a reasonable discount rate utilizing historical trends is critical in the success of LCCA. Table 5.4 shows recent trends in real discount rates for various analysis periods published over the last several years in annual updates to Office of Management and Budget (OMB) Cricular A-94 [18]. Table 5.5 shows trends in nominal discount rates from the same source as mentioned for Table 5.4. Figure 5.4 reflects the historical trend of 10-year interest rates on treasury notes and bonds. The upper curve reflects the nominal rate of return while the lower curve represents the inflation adjusted real rate of return. For the last 10 years (since year 2003), the real rate of return ranges somewhere between 1- to 3-percent and the average close to 2.3 percent. In the report published in 1998, the FHWA has suggested using a real discount rate, one that does not reflect an inflation premium, of 3 to 5 percent in conjunction with real/constant dollar cost estimates. By following the same procedure, ODOT is recommended to use real discount rate of 1 to 3 percent in conjunction with real/constant dollar cost estimates for LCCA.

Table 5.4 Recent Trends in OMB Real Discount Rates

Year	**Analysis Period**					
	3	**5**	**7**	**10**	**20**	**30**
2003	1.6	1.9	2.2	2.5	-	3.2
2004	1.6	2.1	2.4	2.8	3.4	3.5
2005	1.7	2	2.3	2.5	3.0	3.1
2006	2.5	2.6	2.7	2.8	3.0	3.0
2007	2.5	2.6	2.7	2.8	3.0	3.0
2008	2.1	2.3	2.4	2.6	2.8	2.8
2009	0.9	1.6	1.9	2.4	2.9	2.7
2010	0.9	1.6	1.9	2.2	2.7	2.7
2011	0.0	0.4	0.8	1.3	2.1	2.3
2012	0.0	0.4	0.7	1.1	1.7	2.0
Average	**1.38**	**1.75**	**2.00**	**2.30**	**2.73**	**2.83**
Standard Deviation	0.91	0.79	0.71	0.61	0.52	0.44

Table 5.5 Recent Trends in OMB Nominal Discount Rates

Year	Analysis Period					
	3	**5**	**7**	**10**	**20**	**30**
2003	3.1	3.6	3.9	4.2	-	5.1
2004	3.0	3.7	4.2	4.6	5.4	5.5
2005	3.7	4.1	4.4	4.6	5.2	5.2
2006	4.7	4.8	4.9	5.0	5.3	5.2
2007	4.9	4.9	4.9	5.0	5.1	5.1
2008	4.1	4.3	4.4	4.6	4.9	4.9
2009	2.7	3.3	3.7	4.2	4.7	4.5
2010	2.3	3.1	3.5	3.9	4.4	4.5
2011	1.4	1.9	2.4	3.0	3.9	4.2
2012	1.6	2.1	2.5	2.8	3.5	3.8
Average	3.15	3.58	3.88	4.19	4.71	4.80
Standard Deviation	1.21	1.02	0.88	0.76	0.66	0.53

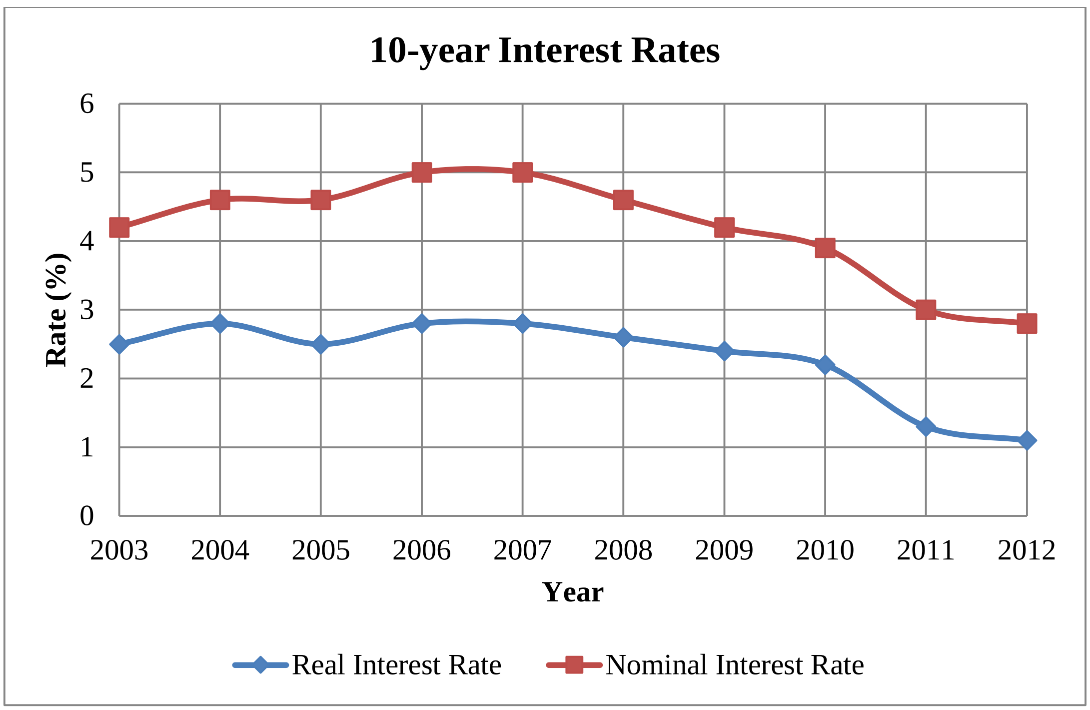


Figure 5.4 Historical Trends on 10-Year Interest Rates on Treasury Notes and Bonds

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Chapter 6 REALISTIC LIFE-CYCLE COST ANALYSIS

In this section, a data mining technique is applied to the historical pavement treatment dataset at Oklahoma Department of Transportation to determine the significant sequential treatment patterns. Association analysis is the identification of items that occur together in a given event or record. This section illustrates how this popular technique in the marketing area can be applied in order to extract useful information and knowledge from historical pavement management data sets.

6.1 Data Mining

Data mining can be defined as a non-trivial extraction of implicit, previously unknown, interesting, and potentially useful information from data [19]. Fayyad et al [20] distinguishes between data mining and KDD by mentioning that the KDD process is the process of using data mining methods (algorithms) to extract (identify) what is deemed knowledge according to the specifications of measures and thresholds. In other words, data mining is mainly concerned with means by which patterns are extracted from data while KDD involves the evaluation and possible interpretation of the patterns to make the decision of what constitutes knowledge and what does not [20]. On the other hand, some research has used data mining and KDD interchangeably because both concentrate on harvesting information from data [21, 22].

Data mining consists of four major techniques utilized depending on the objectives: (a) classification; (b) clustering; (c) numeric prediction; and (d) association. Classification is learning a function that maps a data item into one of several predefined classes. Classification methods have been applied to pavement condition assessment databases in order to classify deteriorations [23, 24]. Numeric prediction is referred to as a combination of techniques such as decision tree, neural network, regression, and ensemble prediction among others. Predictive modeling techniques have been utilized extensively in developing pavement deterioration models and treatment type prediction [22, 25, 26]. Clustering is a common descriptive task where one seeks to identify a finite set of categories or clusters to describe the data [27]. This technique has been applied to pavement management data sets to identify patterns in deterioration of different types of pavement [26]. The purpose of association analysis is to find useful associations and/or correlation relationships among large sets of data items. Association rules, expressed by "if-then" statements, show the attributed value conditions that occur frequently together in a given data set [22, 26]. Although this technique has been applied on pavement condition databases [28, 29], its application on the pavement treatment data set has not been reported.

Data mining has mostly been used by statisticians, data analysts, and the management information system (MIS) communities. Even though this new data analysis process has not been actively employed in the engineering disciplines, the concept of finding hidden patterns from data is not new because many statistical analysis tools have been actively used to solve problems in the engineering domain. Statistical analysis starts with an establishment of a hypothesis, then collects and analyzes data to accept or annul the hypothesis. However, the data mining starts with available data first and then uses the data to solve a problem by selecting and using the most appropriate statistical or artificial intelligence-based prediction models. Data mining is not a simple modeling and prediction process but is a framework for the whole problem solving cycle or process. It is a combination of many algorithms that is chosen based on available data and the problem.

A typical data mining process involves six distinct states as shown in Figure 6.1. These six phases are integrated with each other to make a cycle of the data mining process and the arrows indicate the frequent dependencies between phases. In the problem understanding and data understanding stages, a clear and specific problem is defined. The required and available dataset are identified. The data preparation phase covers all activities to construct the final dataset, which is then fed into the modeling tools from the initial raw data. This phase is a critical stage because the performance of the developed models is highly dependent upon the quality of input data. In this stage, the collected data goes through a data cleaning process to identify any possible mistakes or irregularity in the data and eliminate any outliers. Then, the cleaned dataset goes through the data construction stage in which the dataset is clustered through some techniques such as K-means clustering with principal component analysis (PCA). The key issue in the data construction stage is to discover the true dimensionality of the data. Not all variables are critical and some variables may be highly correlated with each other. The data construction technique will determine the possible number of uncorrelated clusters in the dataset, which can explain most of the variability of the data. In the modeling phase, the actual search for knowledge in the data is performed. In the evaluation phase, the most appropriate model for each cluster can be selected through testing and evaluating all competing models. In the deployment phase, the developed models are actually used for problem solving.

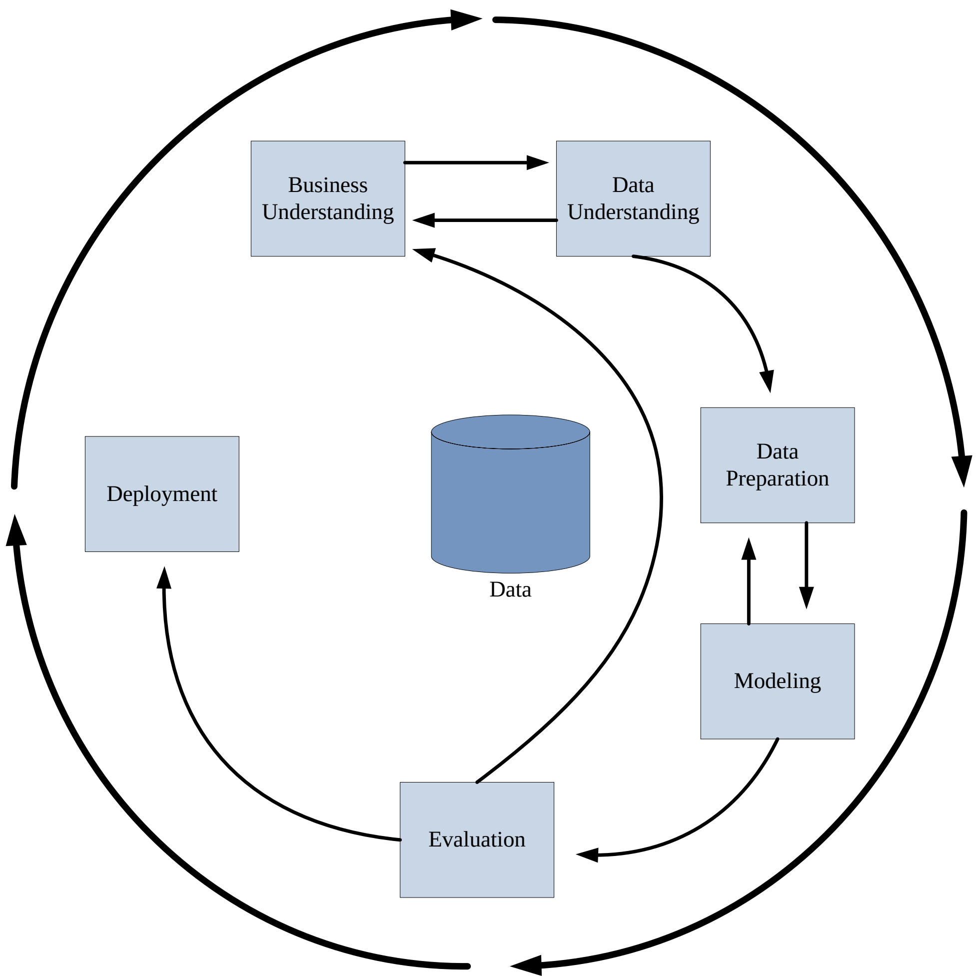


Figure 6.1 Data Mining Process [30]

6.2 Frequent Pattern Mining

Frequent patterns are patterns that appear frequently in a data set. This technique searches for recurring relationships in a given data set. As illustrated in Figure 6.2, this technique can be categorized into association rule mining, sequential pattern mining, and market basket analysis. This section introduces the basic concepts of frequent pattern mining for the discovery of interesting associations and correlations between item sets.

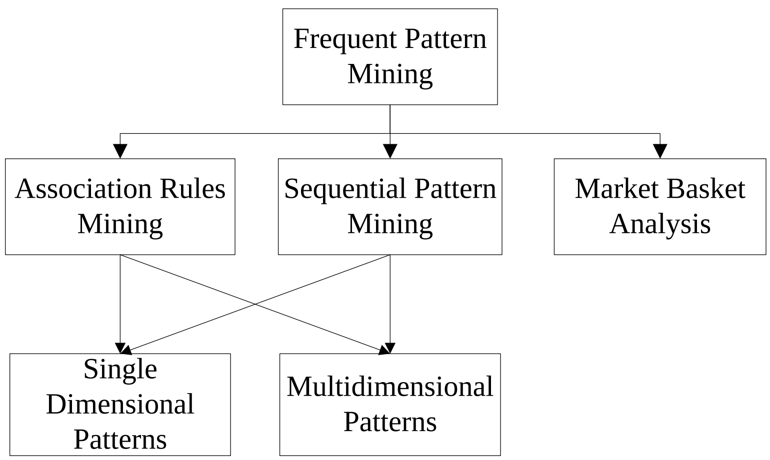


Figure 6.2 Frequent Pattern Mining Techniques

6.3 Market Basket Analysis

Progress in bar code technology has not only helped businesses to handle their products more efficiently, but also enabled agencies to store data that do not necessarily consist of items bought together at the same point of time but it may consist of items bought by a customer over a period of time. This type of data is called basket data.

Market basket analysis is a more general term for retail analysis. Consider a supermarket with a large collection of items. Typical business decisions that the manager of the supermarket has to make include what to put on sale, how to design coupons, how to place merchandise on shelves, and which products to bundle in order to maximize the profit. Market basket analysis analyzes customer habits by finding associations between different items that customers place on their shopping basket. This analysis provides the decision makers with the insight that what items are purchased together by customers. For instance, if customers are buying chips, how likely are they to also buy salsa on the same trip to the supermarket? This information can lead to increased sales by helping retailers design marketing strategies and plan their shelf space accordingly. Items that are frequently purchased together can be placed in proximity to further encourage the combined sale of such items. In an alternative strategy, the associated items can be placed at opposite ends of store in order to expose customers who purchase such items to other items along the way. These two items can also be purchased as a package of chips with salsa or they can be packaged together with poorly selling items in order to increase the sale. As another strategy, price on one can be raised and on the other one can be lowered. This association rule will also necessitate that the manager should not to advertise these products together.

Table 6.1 shows a small transaction data where customers with their purchased products are shown. Item A has been purchased four times, Item B has been purchased three times, item C has been purchased one time, item D has been purchased two times, and item E has been purchased two times. Visual inspection of the example data might reveal the regularity that all four transactions involving item E also involved item A and the two of the four transactions that involved item A also involved item B.

Table 6.1 Hypothetical Market Basket Data

Customer	**Purchased Items**
1	A,B
2	C, A, D
3	A, E
4	A, E, B
5	D,B

6.4 Association Rule Mining

Agrawal et al. [31] developed the earliest form of the association rules mining in order to perform market basket analysis. They introduced a methodology for mining a large collection of basket data type transactions for association rules. The association rules are expressed by “if-then" statements, show attributed value conditions that occur frequently together in a given data set. If the number of possible patterns is small, the set of all possible patterns can be tried in turn and see whether it occurs in data and/or whether it is significant in some sense. But typically it is completely infeasible since for 1,000 items in the data set there are at least 2^{1000} patterns/rules in the data set. Association rule mining finds relationship between item sets. An item set is a set of items. Each transaction is an item set. For example, in the hypothetical basket data shown in Table 6.1, [A, B], [C, A, D] or even combinations that do not occur in the data, such as [B, E] are item sets. Association rule is composed of two item sets called an antecedent and consequent. In the statement that 67% of transactions that purchase B also purchase A, the antecedent item set is [B], and the consequent item set is [A]. The rules are typically displayed with an arrow leading from the antecedent to the consequent: [B] => [A].

Association rules mining start with developing a co-occurrence matrix for pairs of products as shown in Table 6.2. The numbers placed on the diagonal are the number of times a particular item is purchased. As expected, this matrix is symmetric because the number of times that for example item A is purchased together with item B is equal to the number of times that item B is purchased together with Item A. The following simple rules can be generated from this co-occurrence matrix:

- Item A, B and A, E are more likely to be purchased together than any other pair.
- Item C is never purchased with Item B.
- Item E is never purchased with item C or D.

Table 6.2 Co-occurrence Matrix for Pairs of Products

	A	**B**	**C**	**D**	**E**
A	4	2	1	1	2
B	2	3	0	1	1
C	1	0	1	1	0
D	1	1	1	2	0
E	2	1	0	0	2

6.5 Sequential Pattern Mining

The frequent pattern mining that takes the order of events into consideration is called sequential pattern mining. Sequential patterns are frequent subsequences in a sequence of ordered events. It reveals the sequence and structure in the patterns. For example, by studying the order in which items are frequently purchased, we may find that customers tend to first buy a Laptop, followed by a webcam, and then a memory card.

6.6 Applications on Pavement Management Data

Association analysis is the identification of items that occur together in a given event or record. This technique is also known as market basket analysis. Association rules are based on the number of times items occur alone and in combination in the transaction records. An association rule can be expressed as "if item A is part of an event, then item B is also part of the event" with a probability value.

In the marketing area, association analysis is utilized extensively to determine which products are being purchased together by the customers. Major grocery stores utilize the association rules in transaction data sets in order to present items in store displays more efficiently. An example of an association rule might be, "if shoppers buy a jar of salsa, then they buy a bag of tortilla chips." In this example, the antecedent is, "buy a jar of salsa," and the consequent is, "buy a bag of tortilla chips." By substituting pavement sections with customers and treatment types with purchased products, the concept of association can be applied to the historical pavement treatment data set. The goal of this analysis is to identify the treatment types that are associated together and the sequence of their occurrence. This analysis can assist in discovering rehabilitation strategies embedded in historical pavement treatment data sets.

6.6.1 Data Preparation

The interstate structural history data set for Interstate 40 (in Oklahoma) was utilized for the purpose of association analysis. This data set is a record of the construction and major treatment projects on the Interstate 40 in Oklahoma.

All the real-world databases are highly susceptible to noisy, missing, and inconsistent data due to errors in collecting and storing a huge amount of data that needs to be collected in a daily basis. Since low quality data leads to low quality mining, the quality of data is critically important in a data mining process. Therefore, the datasets used for the data mining are preprocessed in order to improve the efficiency and ease of mining process. As indicated in Figure 6.3, the data preprocessing can be categorized into four techniques:

a) Data cleaning (data cleansing)
b) Data integration
c) Data reduction
d) Data transformation

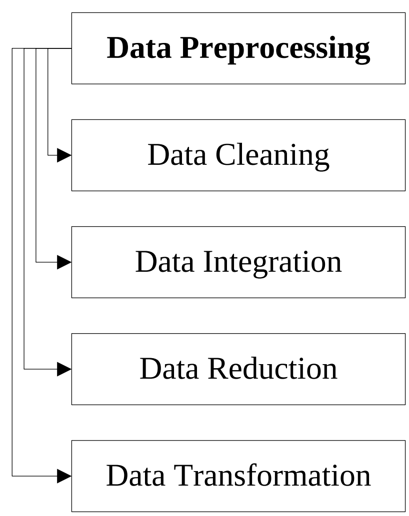


Figure 6.3 Data Preprocessing

The application details of data preparation steps have been discussed in chapter 3 of this report.

6.6.2 Performance Measures

The statistical significance of association rules is measured by certain performance measures. An association rule is accompanied by frequency-based statistics that describe that relationship. The two statistics that are used initially to describe these relationships are support and confidence [31].

Support

Let D be the database of transactions and N be the number of transactions in D. Each transaction D_i is an item set. Support(A=> B) is the proportion of transactions that contain both item sets A and B. In other words, the support of an association rule is the proportion of transactions that contain both the antecedent and the consequent. This performance measure indicates how often the association occurs within the treatment data set. Support is symmetric, meaning that the support of the rule A => B is the same as the support of B => A.

$$Support\ (A => B) = \frac{Support\ (A \cup B)}{All\ Transactions} = P(A \cup B) \qquad \text{Equation 6.1}$$

where; *Support* ($A \cup B$): Transactions that contain both items *A* and *B*

Confidence

The confidence of an association rule is the proportion of transactions containing the antecedent that also contains the consequent. This performance measure indicates the strength of an association. Confidence(A=> B) is the conditional probability that a transaction contains item B, given that it already contains treatment type A. Confidence is not symmetric.

$$Confidence(A => B) = \frac{Support\ (A \cup B)}{Support\ (A)} = P(B|A) \qquad \text{Equation 6.2}$$

Where; *Support* ($A \cup B$): Transactions that contain both items *A* and *B*

Support (*A*): Transactions that contain item *A*

The association rules mining starts with finding all frequent item sets in the data. Each of these item sets will occur at least as frequently as a predetermined minimum support count. Then strong association rules are generated from the frequent item sets. Therefore, these rules satisfy minimum support and minimum confidence. There are also additional significance measures that can be applied for the discovery of correlation relationships between associated items.

A correlation rules is measured not only by its support and confidence but also by the correlation between item sets A and B. There are many different correlation measures from which to choose that are discussed here.

Lift

This performance measure is defined as the ratio of the rule's confidence to the rule's expected confidence. Larger lift ratios tend to indicate more interesting association rules. The occurrence of item set A is independent of the occurrence of item set B if $P(A \cup B) = P(A)P(B)$; otherwise, item sets A and B are dependent and correlated as events. This definition can also be extended to more than two item sets. The lift between the occurrence of A and B can be measured by computing

$$Lift(A => B) = \frac{P(A \cup B)}{P(A)P(B)} = \frac{Confidence(A => B)}{Support(B)} \qquad \text{Equation 6.3}$$

where; *Support* (*B*): Transactions that contain item *B*

Lift is symmetric, meaning that the lift of the rule A => B is the same as the lift of B => A. If the value of lift is less than 1, then the occurrence of A is negatively correlated with the occurrence of B, meaning that the occurrence of one likely leads to the absence of the other one. If the resulting value is greater than 1, then A and B are positively correlated, meaning that the occurrence of one infers the occurrence of the other. If the resulting value is equal to 1, then A and B are independent and there is no correlation between the events. Lift measures the degree that the occurrence of an event lifts the occurrence of the other.

A creditable rule satisfies the minimum support and confidence, and has a value of lift greater than one.

6.7 Pavement Families

The restructured historical pavement treatment data set of Interstate 40 is analyzed by data mining software (SAS® Enterprise Miner*TM*). The association analysis is performed for different pavement families separately. This is based on the assumption that the performances of pavement families are different during the lifecycle of a pavement section. A pavement family is defined as a group of similar pavement sections that are expected to perform similarly and thus share a common performance or a deterioration curve. The current classification of fourteen different pavement families is based on pavement type, traffic volume, and presence of "D" cracking (for JCP only) as shown in Table 6.3 [32].

Table 6.3 Classification of Pavements

Asphalt Pavements (AC)	Concrete Pavements	Composite pavements
a) AC Low Volume – AC with less than 2,000 AADT	e) CRCP Low volume – CRCP with less than 10,000 AADT	l) Composite Low Volume – AC over PC with less than 10,000 AADT
b) AC Moderate Volume – AC with 2,000 – 10,000 AADT	f) CRCP High volume – CRCP with over 10,000 AADT	m) Composite Moderate Volume – with 2,000-10,000 AADT
c) AC High Volume – AC with 10,000 – 40,000 AADT	g) DJCP – Dowel Jointed Concrete Pavement	n) Composite High Volume – with 10,000 AADT
d) AC Very High Volume – AC with over 40,000 AADT	h) DMJCP – Mesh Dowel Jointed Concrete Pavement	
	i) Jointed Plain Concrete Pavement (JPCP) Low Volume – JPCP with less than 10,000 AADT	
	j) JPCP High Volume – with over 10,000 AADT	
	k) JPCP "D" – D cracked JPCP	

The entire sections of Interstate 40 is under a traffic level of more than 10,000 AADT, thus categorized as high traffic volume. As can be seen in Table 6.3 the pavement types are categorized into four different groups based on the pavement material: 1) Asphalt Concrete (AC), 2) Dowel Jointed Concrete Pavement (DJCP), 3) Jointed Plain Concrete Pavement (JPCP), 3) Dowel Mesh Jointed Concrete Pavement (DMJCP), 4) Continuously Reinforced Concrete Pavement (CRCP), and 5) Composite Pavement. The main focus of this study is on asphalt and concrete pavements. Among concrete pavements, association rule mining is performed for DJCP sections only. Both association and sequence analyses are done for each pavement type and a LCCA model is developed for each of them accordingly.

6.8 Asphalt Concrete (AC) Pavement

6.8.1 Association Analysis

The results of association analysis are illustrated in Table 6.4. Only the rules that have a lift value of greater than 1 have been shown in this table. The rules in this table have been sorted based on the support value. The support in the first rule indicates the proportion of pavement sections that contain both treatments Mill_Thin_OL1 and Thin_OL1. A strong rule has a high support and confidence level with a lift value of greater than 1. For this pavement type, there are 20 association rules that have a life value of greater than 1. However, not all of them are considered creditable rules. Larger lift ratios tend to indicate more interesting association rules. Rule no. 12 has the largest lift value. If the lift value is greater than 1, then both sides of the rule are positively correlated, meaning that the occurrence of one infers the occurrence of the other. Lift measures the degree that the occurrence of one treatment lifts the occurrence of the other. The rule, "if Mill_Thin_OL1 is performed, then Thin_OL1 is more likely to occur," has confidence value of 60.38%. The confidence of 60.38% means that if a section is treated by Mill_Thin_OL1, there is a 60.38% chance that the section will also be treated by Thin_OL1. The expected confidence of 44.87% means that 44.87% of all sections are treated by Thin_OL1, regardless of what other treatments are applied. The lift value of 1.35 means that sections treated by Mill_Thin_OL1 are 1.35 times more likely to also be treated by Thin_OL1 as compared to sections that are not treated by Mill_Thin_OL1. This rule is considered as one of the creditable rules because it has a large confidence (60.38%), a large level of support (20.51%), and a value of lift greater than one (1.35).

6.8.2 Sequence Analysis

The sequence analysis reveals the order that treatments are applied on the pavement sections. The goal of sequence analysis is to determine common sequences in time-ordered data. The results of this analysis are utilized to determine the life-cycle cost (LCC) model for the purpose of LCCA. Unlike association analysis, the sequences of events become important by defining the sequence as an input variable in the analysis.

Table 6.4 Association Rules for Asphalt Concrete Pavement

No.	Expected Confidence (%)	Confidence (%)	Support (%)	Lift	Transaction Count	Rule
1	44.87	60.38	20.51	1.35	32	Mill_Thin_OL1 <=> Thin_OL1
2	40.38	66.67	12.82	1.65	20	Mill_Med_OL4 <=> OGFC
3	40.38	89.47	10.90	2.22	17	Mill_Thick_OL1 <=> OGFC
4	44.87	75.00	9.62	1.67	15	Level_OGFC <=> Thin_OL1
5	44.87	77.78	8.97	1.73	14	Mill_Med_OL3 <=> Thin_OL1
6	44.87	46.43	8.33	1.03	13	Mill_Med_OL1 <=> Thin_OL1
7	44.87	60.00	7.69	1.34	12	Mill_Thick_OL3 <=> Thin_OL1
8	44.87	54.55	7.69	1.22	12	Mill_Thin_OL3 <=> Thin_OL1
9	40.38	42.86	7.69	1.06	12	Mill_Med_OL1 <==> OGFC
10	40.38	42.86	7.69	1.06	12	Microsurface <=> OGFC
11	33.97	55.00	7.05	1.62	11	Mill_Thick_OL3 <=> Mill_Thin_OL1
12	11.54	83.33	6.41	7.22	10	Thin_OL1 & Mill_Thin_OL3 <=> Mill_Med_OL3
13	14.10	71.43	6.41	5.06	10	Thin_OL1 & Mill_Med_OL3 <=> Mill_Thin_OL3
14	12.82	62.50	6.41	4.88	10	UTBWC <=> Thin_OL3
15	12.82	52.63	6.41	4.11	10	Mill_Thick_OL1 <=> OGFC & Mill_Med_OL4
16	14.10	55.56	6.41	3.94	10	Mill_Med_OL3 <=> Mill_Thin_OL3
17	19.23	58.82	6.41	3.06	10	OGFC & Mill_Thick_OL1 <=> Mill_Med_OL4
18	19.23	52.63	6.41	2.74	10	Mill_Thick_OL1 <=> Mill_Med_OL4
19	40.38	100.00	6.41	2.48	10	Mill_Thick_OL1 & Mill_Med_OL4 <=> OGFC
20	44.87	100.00	6.41	2.23	10	Mill_Thin_OL3 & Mill_Med_OL3 <=> Thin_OL1

The results of the analysis and generated rules are shown in Table 6.5. The rules are sorted based on the confidence value. Rules have been separated based on the number of treatments that are included in them. The first 12 rules have 2 treatments and the rest of the rules have 3 treatments. For the 2 treatment rules only rules with support value of greater than 7% are shown in this table. For 3 treatment rules only rules with support value of greater than 5% are shown in this table. This is based on the assumption that rules with support percentage of less than 7% for two treatment rules and 5% for three treatment rules are not creditable. Since all the rules with more than 3 treatments have support value of less than 5% they are not included in this table. The definition of support and confidence are the same as in association analysis except the fact that the sequence of events makes a difference in the analysis.

Table 6.5 Summary of the Sequence Analysis Results

No.	Transaction Count	Support (%)	Confidence (%)	Rule
1	32	20.92	45.71	Thin_OL1 ==> Mill_Thin_OL1
2	20	13.07	31.75	OGFC ==> Mill_Med_OL4
3	17	11.11	26.98	OGFC ==> Mill_Thick_OL1
4	14	9.15	26.42	Mill_Thin_OL1 ==> Mill_Thin_OL1
5	15	9.80	21.43	Thin_OL1 ==> Level_OGFC
6	11	7.19	20.75	Mill_Thin_OL1 ==> Mill_Thick_OL3
7	13	8.50	20.63	OGFC ==> Mill_Thin_OL1
8	14	9.15	20.00	Thin_OL1 ==> Mill_Med_OL3
9	12	7.84	19.05	OGFC ==> Microsurface
10	12	7.84	19.05	OGFC ==> Mill_Med_OL1
11	13	8.50	18.57	Thin_OL1 ==> Mill_Med_OL1
12	11	7.19	17.46	OGFC ==> Thin_OL1
13	12	7.84	17.14	Thin_OL1 ==> Mill_Thick_OL3
14	12	7.84	17.14	Thin_OL1 ==> Mill_Thin_OL3
15	10	6.54	83.33	OGFC ==> Microsurface ==> Microsurface
16	10	6.54	50.00	OGFC ==> Mill_Med_OL4 ==> Mill_Thick_OL1
17	8	5.23	40.00	OGFC ==> Mill_Med_OL4 ==> Mill_Med_OL1
18	8	5.23	25.00	Thin_OL1 ==> Mill_Thin_OL1 ==> Mill_Thin_OL1
19	8	5.23	57.14	Thin_OL1 ==> Mill_Med_OL3 ==> Mill_Thin_OL3

The rules with both large support and confidence values are considered creditable rules. The rule, “if Thin_OL1, then Mill_Thin_OL1,” is the most creditable rule due to its large confidence (45.71%) and level of support (20.92%). Figure 6.4 shows a scatter plot of rules identified in

Table 6.5. In this figure rules are plotted against support and confidence values. Rules that are closer to the upper right corner of the plot are stronger.

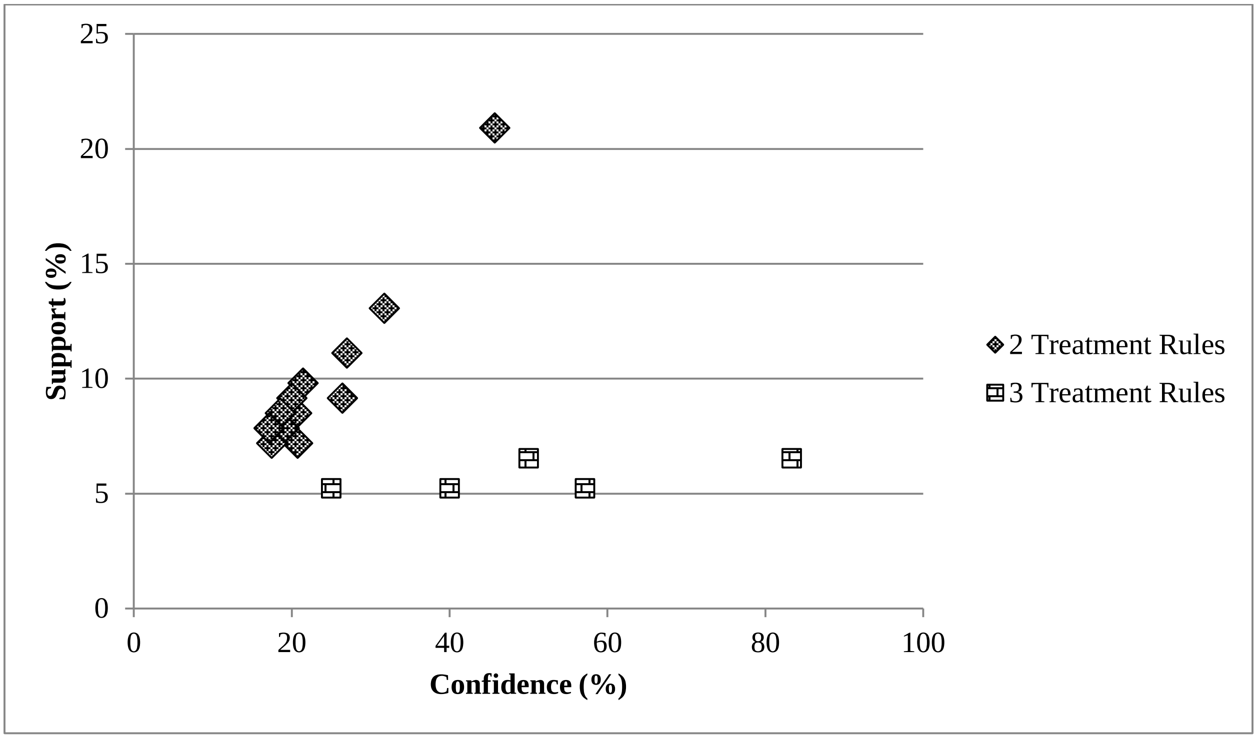


Figure 6.4 Scatter Plot of Rules Based on Support vs. Confidence Values

A graphic representation of the sequence analysis can be seen in Figure 6.5. The nodes in this graph indicate treatment activities. The diameter of the nodes is correlated with the number of times that the treatment activities have occurred in the data set. For AC pavement sections in Interstate 40, Thin_OL1, OGFC, and Mill_Thin_OL1 are the major treatment activities that have occurred the most in the data set. The thickness of links between nodes identifies the strength of association between treatment activities. As can be seen in this figure, there is a strong association between Thin_OL1 and Mill_Thin_OL1. The direction of the arrow head between Thin_OL1 and Mill_Thin_OL1 indicates that Thin_OL1 occur as the first treatment activity. By looking at the direction of all the links between treatment activities, it can be inferred that Thin_OL1 and OGFC are the two treatment activities that are very likely to occur as the first treatment.

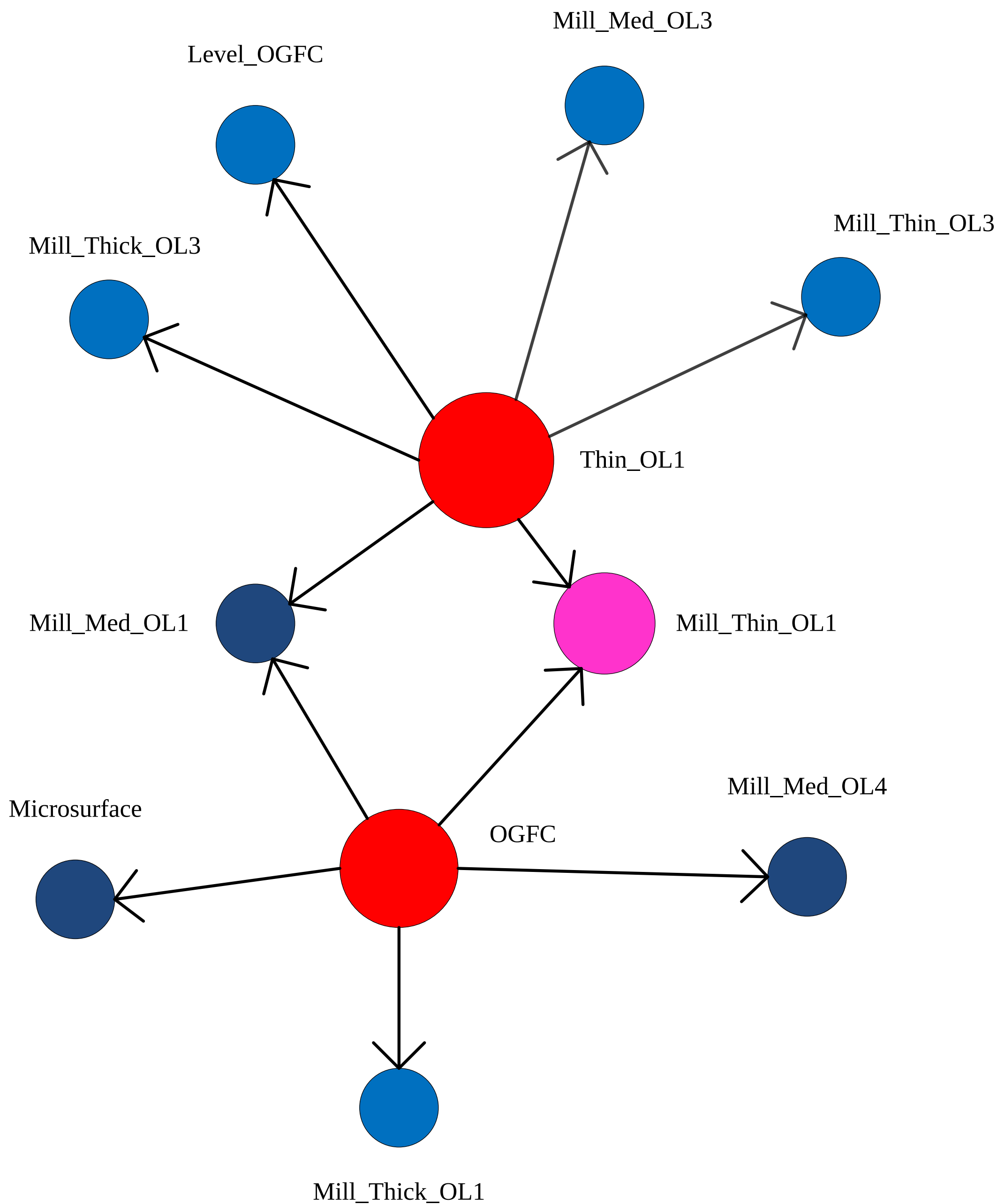


Figure 6.5 Summary of the Association Analysis Results

6.8.3 Frequency Analysis

The relationships between different treatment types were studied, and strong sequences were identified. For instance, it was revealed from the sequence analysis that "if Thin_OL1, then Mill_Thin_OL1," is a strong rule. But whether OGFC is likely to occur as the first, second, third, fourth, or fifth treatment on AC pavement has not been discovered yet. In addition, the confidence is a conditional probability which identifies the probability of occurrence of Mill_Thin_OL1 if Thin_OL1 is known to occur as the first treatment. Whereas, we are interested in calculating the probability that A and B occur together. For the rule "if A, then B" the confidence is as follows:

$$Confidence(A => B) = \frac{transactions\ that\ contain\ both\ items\ A\ and\ B}{transactions\ that\ contain\ item\ A} = P(B|A) \qquad \text{Equation 6.4}$$

According to general multiplication rule for dependent events in probability theory we have

$$P(A \cap B) = P(A) * P(B|A) \qquad \text{Equation 6.5}$$

Therefore, we first need to determine the probability of occurrence of event A. In the previous example event A would be Thin_OL1.

In order to address this issue, frequencies of each treatment type are broken down based on the order of treatment. For instance, the number of times that Thin_OL1 occurs as the first, second, third, fourth, and fifth treatment are counted and plotted with other treatment types.

Figure 6.6 shows the frequency distributions of treatment types based on their time of occurrence. The major treatment types for AC pavement are listed on the horizontal axis of this figure. A tabular illustration of this figure is also available in Table 6.6. For the first treatment, OGFC (36.6%) and Thin_OL1 (35.9%) are the most common treatment activities. Microsurface (14.6%), Level_OGFC (11.9%), Mill_Med_OL4 (11.9%), and Thin_OL1 (11.9%) are the treatment types that have mostly occurred as the second treatment. Mill_Thin_OL1 (19.0%), Mill_Med_OL1 (12.0%), and Mill_Thin_OL3 (11.3%) are the most common treatments in the third order. The treatments that are likely to occur as the fourth treatment are Mill_Thin_OL1 (20.7%), UTBWC (16.1%), and Mill_Thick_OL1 (11.5%). And finally, Mill_Thin_OL1 (23.5%), Mill_Med_OL2 (23.5%) and Mill_Thick_OL3 (17.6%) tend to be used as the fifth treatment on AC pavements.

By combining the results of the association and sequence analyses with frequency analysis, the treatment strategies embedded in the data set for AC pavements are revealed as illustrated in Figure 6.7. Treatment types are linked together based on the rules identified during the sequence analysis. The numbers shown in the figure refer to the rule numbers identified in Table 6.5. Some of the rules developed in the sequence analysis are two treatment rules and some of them are three treatment rules. The two treatment rules do not necessarily start from the first treatment. For instance, rules no. 4, no. 13, and no. 14 indicate a relationship between the second and the third treatments. Other rules such as rule no. 3, no. 10, and no. 11 indicate a relationship between the first and the third treatments. In addition, the majority of rules belong to the first three treatment activities because the number of pavement sections that have undergone four or five treatment activities in their life-cycle is few and these relationships have been filtered out from the results.

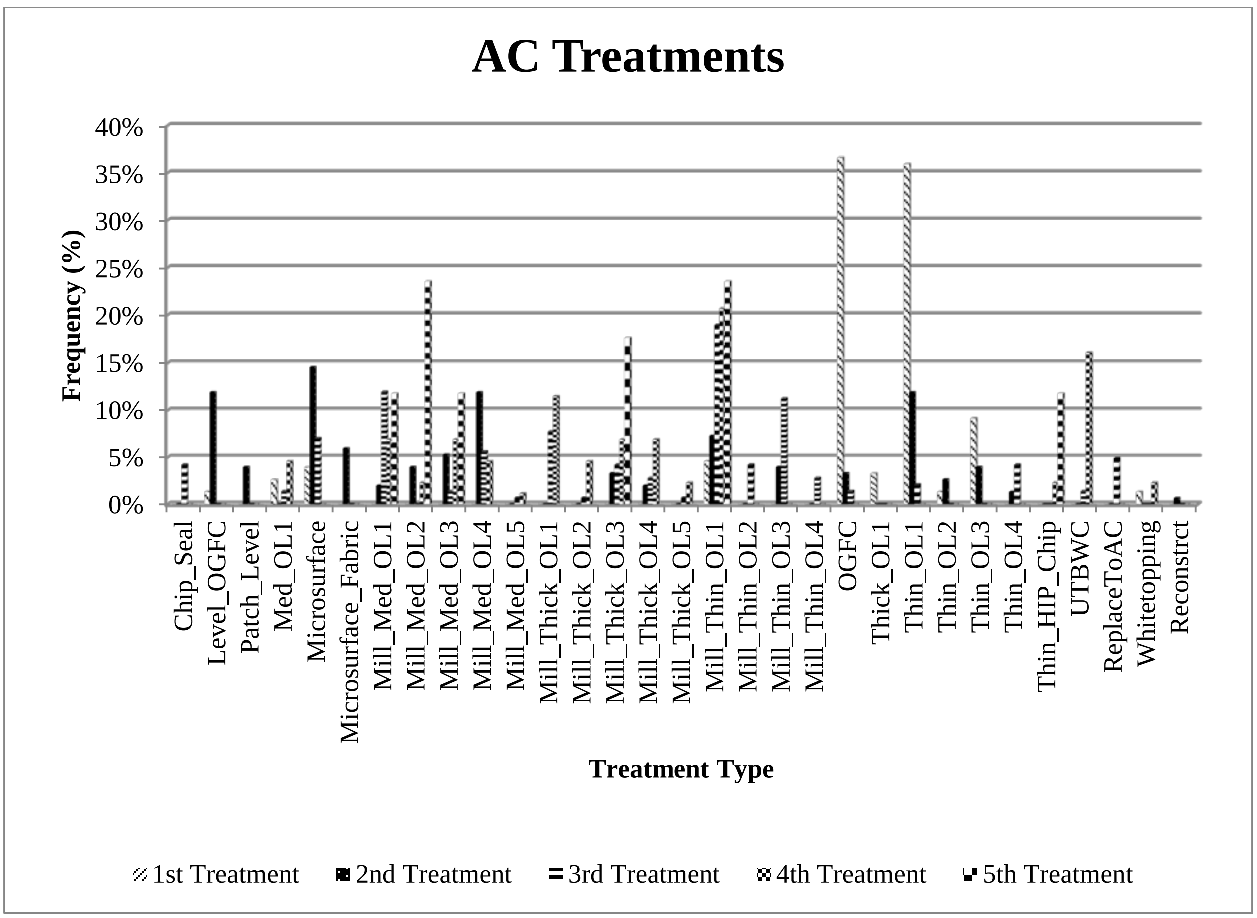


Figure 6.6 Frequency Distributions of AC Pavement Treatment Types Based on Time of Occurrence

Table 6.6 Frequency of AC Pavement Treatment Types

Treatments	1st Treatment		2nd Treatment		3rd Treatment		4th Treatment		5th Treatment	
Chip_Seal	0	0.0%	0	0.0%	6	4.2%	0	0.0%	0	0.0%
Level_OGFC	2	1.3%	18	**11.9%**	0	0.0%	0	0.0%	0	0.0%
Patch_Level	0	0.0%	6	4.0%	0	0.0%	0	0.0%	0	0.0%
Med_OL1	4	2.6%	0	0.0%	2	1.4%	4	4.6%	0	0.0%
Microsurface	6	3.9%	22	**14.6%**	10	7.0%	0	0.0%	0	0.0%
Microsurface_Fabric	0	0.0%	9	6.0%	0	0.0%	0	0.0%	0	0.0%
Mill_Med_OL1	0	0.0%	3	2.0%	17	**12.0%**	6	6.9%	2	11.8%
Mill_Med_OL2	0	0.0%	6	4.0%	0	0.0%	2	2.3%	4	**23.5%**
Mill_Med_OL3	0	0.0%	8	5.3%	2	1.4%	6	6.9%	2	11.8%
Mill_Med_OL4	0	0.0%	18	**11.9%**	8	5.6%	4	4.6%	0	0.0%
Mill_Med_OL5	0	0.0%	0	0.0%	1	0.7%	1	1.1%	0	0.0%
Mill_Thick_OL1	0	0.0%	0	0.0%	11	7.7%	10	**11.5%**	0	0.0%
Mill_Thick_OL2	0	0.0%	0	0.0%	1	0.7%	4	4.6%	0	0.0%
Mill_Thick_OL3	0	0.0%	5	3.3%	6	4.2%	6	6.9%	3	17.6%
Mill_Thick_OL4	0	0.0%	3	2.0%	4	2.8%	6	6.9%	0	0.0%
Mill_Thick_OL5	0	0.0%	0	0.0%	1	0.7%	2	2.3%	0	0.0%
Mill_Thin_OL1	7	4.6%	11	7.3%	27	**19.0%**	18	**20.7%**	4	**23.5%**
Mill_Thin_OL2	0	0.0%	0	0.0%	6	4.2%	0	0.0%	0	0.0%
Mill_Thin_OL3	0	0.0%	6	4.0%	16	**11.3%**	0	0.0%	0	0.0%
Mill_Thin_OL4	0	0.0%	0	0.0%	4	2.8%	0	0.0%	0	0.0%
OGFC	56	**36.6%**	5	3.3%	2	1.4%	0	0.0%	0	0.0%
Thick_OL1	5	3.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Thin_OL1	55	**35.9%**	18	**11.9%**	3	2.1%	0	0.0%	0	0.0%
Thin_OL2	2	1.3%	4	2.6%	0	0.0%	0	0.0%	0	0.0%
Thin_OL3	14	9.2%	6	4.0%	0	0.0%	0	0.0%	0	0.0%
Thin_OL4	0	0.0%	2	1.3%	6	4.2%	0	0.0%	0	0.0%
Thin_HIP_Chip	0	0.0%	0	0.0%	0	0.0%	2	2.3%	2	11.8%
UTBWC	0	0.0%	0	0.0%	2	1.4%	14	**16.1%**	0	0.0%
ReplaceToAC	0	0.0%	0	0.0%	7	4.9%	0	0.0%	0	0.0%
Whitetopping	2	1.3%	0	0.0%	0	0.0%	2	2.3%	0	0.0%
Reconstrct	0	0.0%	1	0.7%	0	0.0%	0	0.0%	0	0.0%
Total	**153**	**100.0%**	**151**	**100.0%**	**142**	**100.0%**	**87**	**100.0%**	**17**	**100.0%**

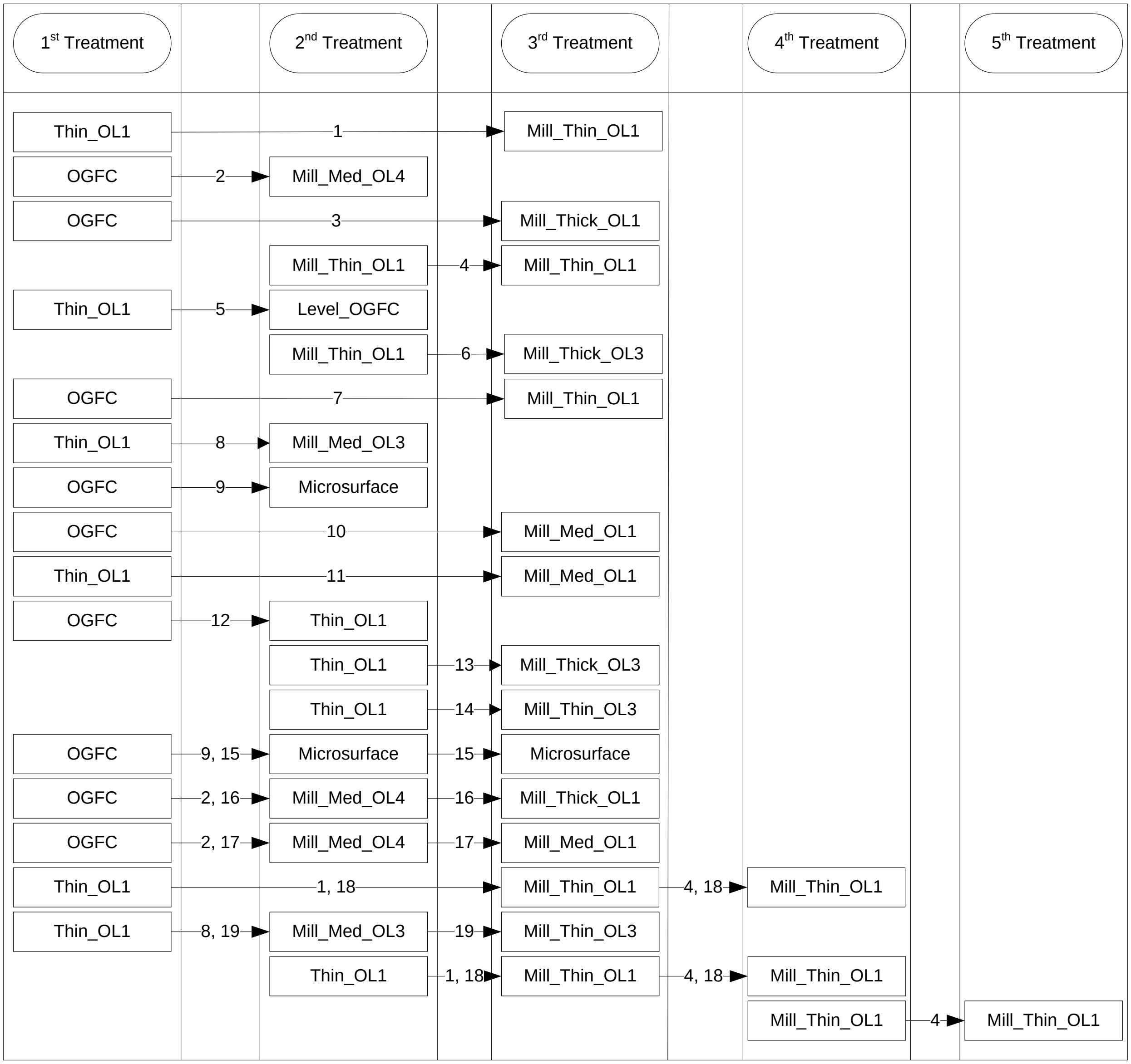


Figure 6.7 AC Pavement Treatment Strategies

The data used in the analysis consist of all the AC pavement sections of Interstate 40 which have been under very high traffic volume during their life-cycle (i.e. the same pavement family). However, it was found out that many pavement sections that belong to the same pavement family have undergone different treatment strategies during their life-cycles. The results of this analysis indicate that the traditional approach of the SHAs, by assuming one LCC model for each pavement type, needs to be revised.

6.8.4 Realistic LCCA Model

The rules identified in Figure 6.7 are summarized into 9 rules as indicated in Figure 6.8. Only the rules that indicate a relationship between the first three treatment activities are considered in the final LCCA model. Rules such as no. 3 that relates first treatment to the third treatment and rules such as no. 4 that relates the second treatment to the third treatment are ignored. It should be noted that summarizing rules do not mean that these rules are not considered in the model. For instance, rule no. 4 is part of rule no. 18 or rule no. 10 is part of rule no. 17.

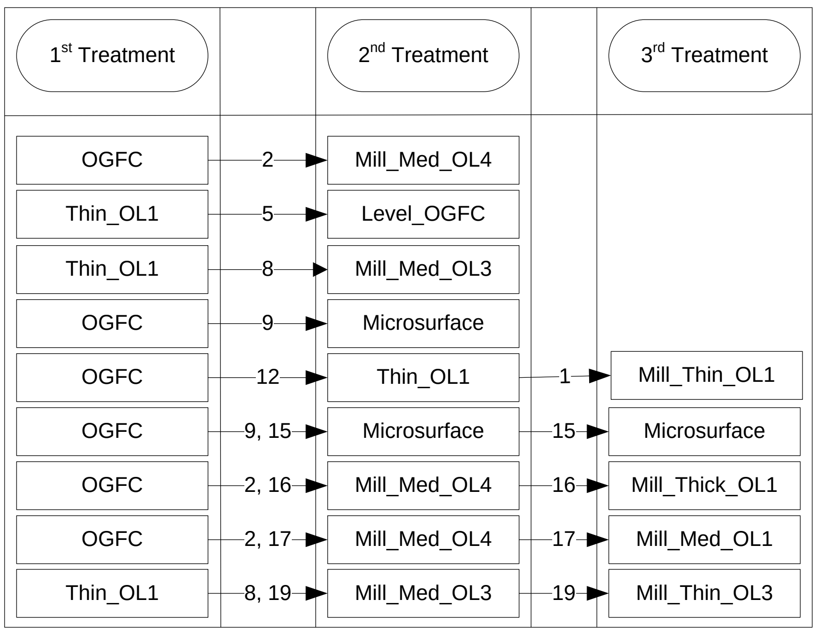


Figure 6.8 Summarized Realistic LCCA Model for AC Pavements

Realistic LCCA model is based upon the realistic LCC models developed during the association and sequence analyses. In realistic LCCA model, possible treatment strategies are assigned a probability of occurrence, and the final LCC is the weighted summation of individual net present values (NPVs). We are interested in calculating the probability that A and B occur together.

The probability of occurrence is obtained by multiplying the confidence level by the probability of event A. For the rules generated for AC pavement sections, OGFC and Thin_OL1 are the only possible treatment options as the first treatment and their likelihood of occurrence is the same. In other words, there is 50% chance that each one of these treatments is applied on AC pavement section as the first treatment. Therefore the probability of occurrence is calculated by multiplying confidence by 0.5 for each rule in Figure 6.8. Then these probabilities are normalized in order to have summation of equal to 100%. Probabilities of occurrence can be seen in Table 6.7. It should be noted that some two treatment rules are not considered in the final LCCA model because they are accounted for in three treatment rules. For example rule no. 8 is part of rule no. 19 or rule no. 9 is part of rule no. 15 or rule no. 2 is part of rule no. 16.

Table 6.7 Final Realistic LCCA Model for AC Pavement

Rule No.	Rule	Support (%)	Confidence (%)	Probability
15	OGFC=>Microsurface=>Microsurface	6.54	83.33	30.94%
19	Thin_OL1=>Mill_Med_OL3=>Mill_Thin_OL3	5.23	57.14	21.21%
16	OGFC=>Mill_Med_OL4=>Mill_Thick_OL1	6.54	50	18.56%
17	OGFC=>Mill_Med_OL4=>Mill_Med_OL1	5.23	40	14.85%
5	Thin_OL1=>Level_OGFC	9.8	21.43	7.96%
12	OGFC=>Thin_OL1=>Mill_Thin_OL1	7.19	17.46	6.48%

Table 6.8 shows the timing of treatment strategies developed for AC pavement sections. As can be seen in this table, regardless of the type of first treatment (OGFC or Thin_OL1), the average time to the first treatment is 10.8 years. However, the average time to the second treatment depends upon the type of that treatment. For instance, in rule no. 15 the first treatment is applied 10.8 years after construction of the section. This is the same for all the treatment strategies starting with OGFC. However, based on the type of the second and the third treatments, average time to the second and the third treatments vary. According to rule no. 15 the section is treated with Microsurface 6.5 years later than the first treatment. Finally Microsurface is applied again as the third treatment 9 years after the second treatment. For rule no. 16 the second treatment which is Mill_Med_OL4 is applied 14 years later than the first treatment activity.

6.9 Dowel Jointed Concrete Pavement (DJCP)

6.9.1 Association Analysis

The results of association analysis are illustrated in Table 6.9. This table shows all the rules generated by association analysis. The rules in this table have been sorted based on the support value. The support in the first rule indicates the proportion of pavement sections that contain both treatments Joint_Rehab and Unbonded_Overlay. A strong rule has a high support and confidence level with a lift value of greater than 1. For this pavement type, there are 32 association rules with a lift value of greater than 1. However, not all of them are considered creditable rules. Larger lift ratios tend to indicate more interesting association rules. Rules from no.2 to no.12 have the largest lift value. If the lift value is greater than 1, then both sides of the rule are positively correlated, meaning that the occurrence of one infers the occurrence of the other. Lift measures the degree that the occurrence of one treatment lifts the occurrence of the other. The rule, "if Joint_Rehab is performed, then Unbonded_Overlay is more likely to occur," has confidence value of 33.33%. The confidence of 33.33% means that if a section is treated by Joint_Rehab, there is 33.33% chance that the section will also be treated by Unbonded_Overlay. The expected confidence of 11.76% means that 11.76% of all sections are treated by Unbonded_Overlay, regardless of what other treatments are applied. The lift value of 2.8 means that sections treated by Joint_Rehab are 2.8 times more likely to also be treated by Unbonded_Overlay as compared to sections that are not treated by Joint_Rehab. This rule is considered as the most creditable rule for DJCP sections because it has a large confidence (33.33%), a large level of support (11.76%), and a value of lift greater than one (2.8).

Table 6.8 Timing of Realistic LCCA Model for AC Pavement

Rule No.	**Rule**	**Time to the 1st Treatment (years)**	**Time to the 2nd Treatment (years)**	**Time to the 3rd Treatment (years)**
15	OGFC=>Microsurface=>Microsurface	10.8	6.5	9.0
19	Thin_OL1=>Mill_Med_OL3=>Mill_Thin_OL3	10.8	12	10.0
16	OGFC=>Mill_Med_OL4=>Mill_Thick_OL1	10.8	14	16.0
17	OGFC=>Mill_Med_OL4=>Mill_Med_OL1	10.8	14	14.3
5	Thin_OL1=>Level_OGFC	10.8	7	-
12	OGFC=>Thin_OL1=>Mill_Thin_OL1	10.8	7.3	-
Average		10.8	10.4	12.3

Table 6.9 Association Rules for DJCP

No	Expected Confidence (%)	Confidence (%)	Support (%)	Lift	Transaction Count	Rule
1	11.76	33.33	11.76	2.8	4	Joint_Rehab <=> Unbonded_Overlay
2	5.88	100.00	5.88	17.0	2	Med_OL3 <=> Mill_Thin_OL1
3	5.88	100.00	5.88	17.0	2	ReplacetoDJCP <=> Reconstruction & Grind
4	5.88	100.00	5.88	17.0	2	Joint_Seal <=> Reconstruction & Grind_Seal
5	5.88	100.00	5.88	17.0	2	ReplacetoDJCP <=> Reconstruction & Joint_Rehab
6	5.88	100.00	5.88	17.0	2	Grind <=> Reconstruction & Joint_Rehab
7	5.88	100.00	5.88	17.0	2	Grind <=> ReplacetoDJCP
8	5.88	100.00	5.88	17.0	2	Reconstruction & Joint_Rehab <=> ReplacetoDJCP
9	5.88	100.00	5.88	17.0	2	Reconstruction & Grind <=> ReplacetoDJCP
10	5.88	100.00	5.88	17.0	2	Joint_Rehab & Grind <=> ReplacetoDJCP
11	5.88	100.00	5.88	17.0	2	Grind <=> ReplacetoDJCP & Joint_Rehab
12	5.88	100.00	5.88	17.0	2	Grind <=> ReplacetoDJCP & Reconstruction
13	5.88	50.00	5.88	8.5	2	Grind_Seal <=> Joint_Seal
14	11.76	100.00	5.88	8.5	2	ReplacetoDJCP <=> Reconstruction
15	11.76	100.00	5.88	8.5	2	Joint_Seal <=> Reconstruction
16	11.76	100.00	5.88	8.5	2	Grind <=> Reconstruction
17	11.76	100.00	5.88	8.5	2	ReplacetoDJCP & Joint_Rehab <=> Reconstruction
18	11.76	100.00	5.88	8.5	2	ReplacetoDJCP & Grind <=> Reconstruction
19	11.76	100.00	5.88	8.5	2	Joint_Seal & Grind_Seal <=> Reconstruction
20	11.76	100.00	5.88	8.5	2	Joint_Rehab & Grind <=> Reconstruction
21	5.88	50.00	5.88	8.5	2	Grind_Seal <=> Reconstruction & Joint_Seal
22	11.76	50.00	5.88	4.3	2	Grind_Seal <=> Reconstruction
23	11.76	50.00	5.88	4.3	2	PC_Patch <=> Thin_OL1
24	35.29	100.00	5.88	2.8	2	Grind <=> Joint_Rehab
25	5.88	16.67	5.88	2.8	2	Joint_Rehab <=> Reconstruction & Grind
26	5.88	16.67	5.88	2.8	2	Joint_Rehab <=> ReplacetoDJCP
27	5.88	16.67	5.88	2.8	2	Joint_Rehab <=> ReplacetoDJCP & Grind
28	5.88	16.67	5.88	2.8	2	Joint_Rehab <=> ReplacetoDJCP & Reconstruction
29	11.76	16.67	5.88	1.4	2	Joint_Rehab <=> Grind_Seal
30	35.29	50.00	5.88	1.4	2	Grind_Seal <=> Joint_Rehab
31	11.76	16.67	5.88	1.4	2	Joint_Rehab <=> Reconstruction

6.9.2 Sequence Analysis

The results of the sequence analysis and generated rules are shown in Table 6.10. The rules are sorted based on the confidence value. The number of rules generated in the analysis is 24. Not all of these 24 rules are considered creditable. As can be seen in the table, the first two rules have large support and confidence values. The other rules are only based on two pavement sections which might decrease their creditability. Although the confidence of rule no. 5 is 100%, it has only occurred in two pavement sections.

The rules with both large support and confidence values are considered creditable rules. The rule, "if Thin_OL1, then Thin_OL1," is the most creditable rule due to its large confidence (100%) and level of support (16.67%). Figure 6.9 shows a scatter plot of rules identified in Table 6.10. In this figure rules are plotted against support and confidence values. Rules that are closer to the upper right corner of the plot are stronger.

A graphic representation of the sequence analysis can be seen in Figure 6.10. The nodes in this graph indicate treatment activities. The diameter of the nodes is correlated with the number of times that the treatment activities have occurred in the data set. For DJCP sections in Interstate 40, Joint_Rehab is the major treatment activity that has occurred the most in the data set. The thickness of links between nodes identifies the strength of association between treatment activities. As can be seen in this figure, there is a strong association between Joint_Rehab and ReplacetoDJCP. The direction of the arrow head between Med_OL3 and Mill_Thin_OL1 indicates that Med_OL3 occurs as the first treatment activity. By looking at the direction of all the links between treatment activities, it can be inferred that the treatment strategies are more diverse than AC pavements. Also some flexible treatment has also been applied on DJCP sections such as Med_OL3, Mill_Thin_OL1 and Thin_OL1. As can be seen in this figure, Joint_Rehab, Joint_Seal, Med_OL3, and Thin_OL1 are always the preceding treatment activity. On the other hand Unbonded_Overlay, Reconstruction, Mill_thin_OL1, and PC_Patch tend to be the last chain of treatment activities on the DJCP sections.

Table 6.10 Summary of the Sequence Analysis Results for DJCP Sections

Rule No.	Transaction Count	Support (%)	Confidence (%)	Rule
1	4	16.67	100	Thin_OL1 => Thin_OL1
2	4	16.67	33.33	Joint_Rehab => Unbonded_Overlay
3	2	8.33	16.67	Joint_Rehab => Grind
4	2	8.33	16.67	Joint_Rehab => Grind_Seal
5	2	8.33	100	Joint_Seal => Grind_Seal
6	2	8.33	16.67	Joint_Rehab => Joint_Rehab
7	2	8.33	100	Med_OL3 => Mill_Thin_OL1
8	2	8.33	50	Thin_OL1 => PC_Patch
9	2	8.33	100	Grind => Reconstruction
10	2	8.33	50	Grind_Seal => Reconstruction
11	2	8.33	16.67	Joint_Rehab => Reconstruction
12	2	8.33	100	Joint_Seal => Reconstruction
13	2	8.33	100	ReplacetoDJCP => Reconstruction
14	2	8.33	100	Grind => ReplacetoDJCP
15	2	8.33	16.67	Joint_Rehab => ReplacetoDJCP
16	2	8.33	100	Joint_Rehab => Joint_Rehab => Grind
17	2	8.33	50	Thin_OL1 => Thin_OL1 => PC_Patch
18	2	8.33	100	Joint_Rehab => Grind => Reconstruction
19	2	8.33	100	Joint_Seal => Grind_Seal => Reconstruction
20	2	8.33	100	Joint_Rehab => Joint_Rehab => Reconstruction
21	2	8.33	100	Grind => ReplacetoDJCP => Reconstruction
22	2	8.33	100	Joint_Rehab => ReplacetoDJCP => Reconstruction
23	2	8.33	100	Joint_Rehab => Grind => ReplacetoDJCP
24	2	8.33	100	Joint_Rehab => Joint_Rehab => ReplacetoDJCP

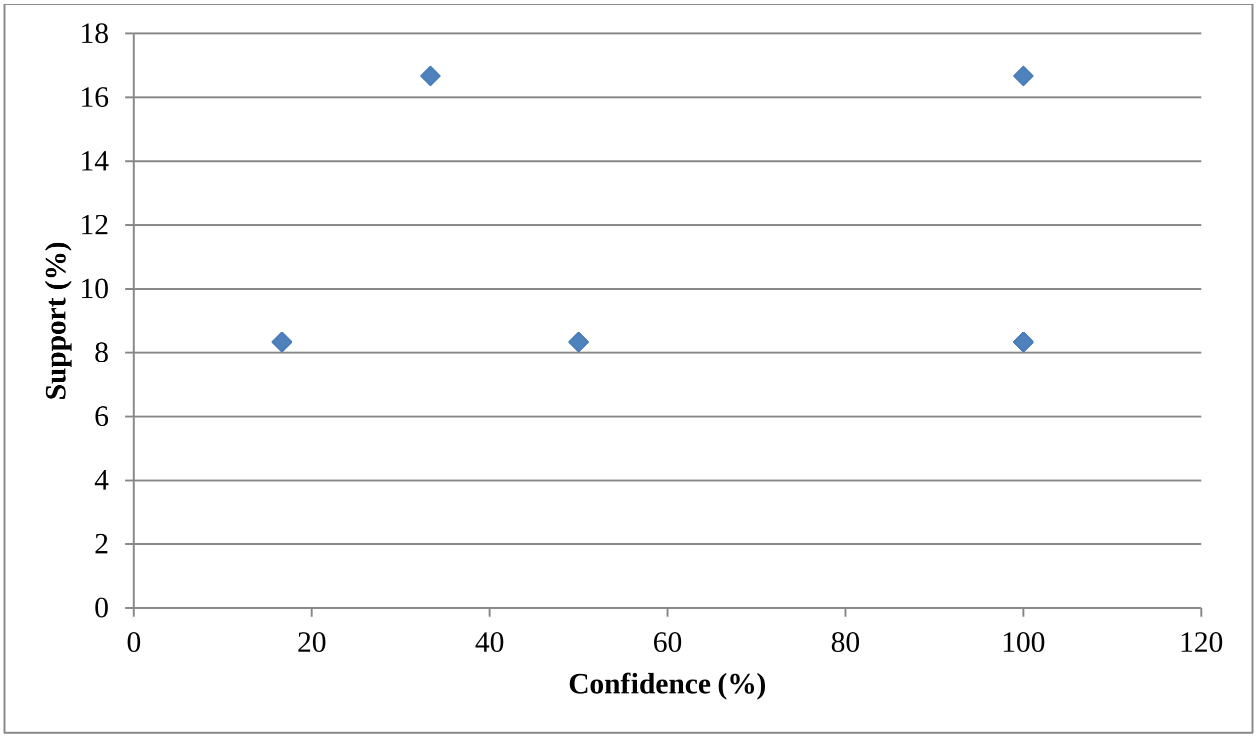


Figure 6.9 Scatter Plot of Rules Based on Support vs. Confidence Values for DJCP

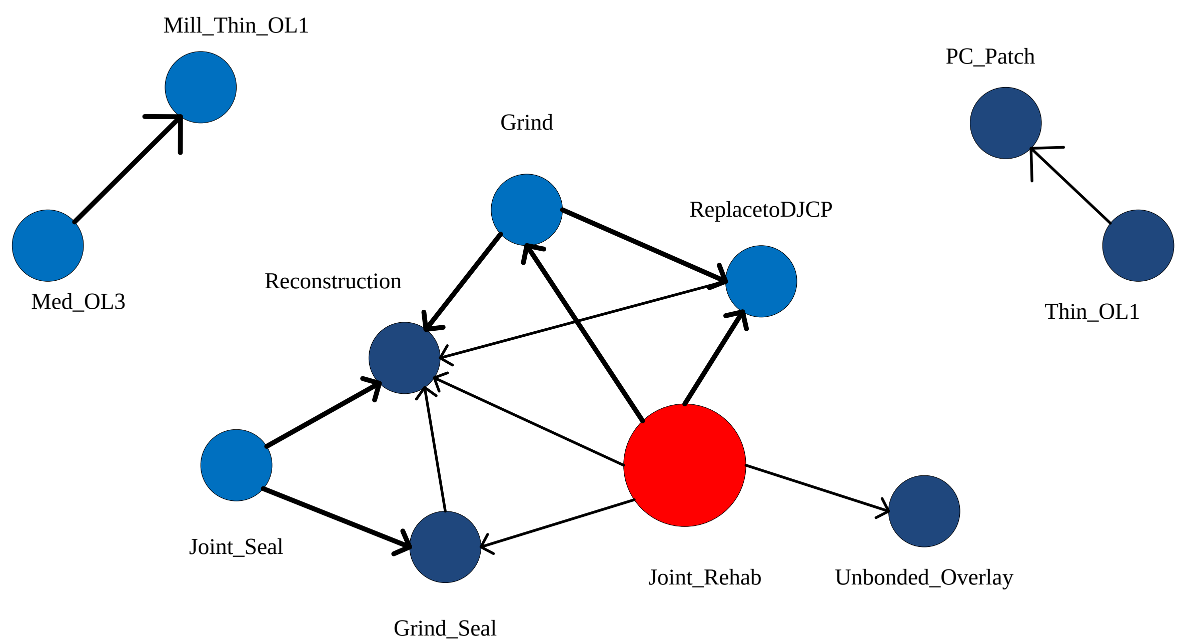


Figure 6.10 Link Graph of Sequence Analysis for DJCP

6.9.3 Frequency Analysis

The relationships between different treatment types were studied, and strong sequences were identified. For instance, it was revealed from the sequence analysis that "if Joint_Rehab, then Unbonded_Overlay," is a strong rule. But whether Joint_Rehab is likely to occur as the first, second, third, or fourth treatment on DJPC sections has not been discovered yet. In addition, the confidence is a conditional probability which identifies the probability of occurrence of Unbonded_Overlay if Joint_Rehab is known to occur as the first treatment.

Since we are interested in calculating the probability that both treatments occur together, we first need to determine the probability of occurrence of event A. In the previous example event A would be Joint_Rehab. In order to address this issue, frequencies of each treatment type are broken down based on the order of treatment. For instance, the number of times that Joint_Rehab occurs as the first, second, third, fourth, and fifth treatment are counted and plotted with other treatment types.

Figure 6.11 shows the frequency distributions of treatment types based on their time of occurrence. The major treatment types for DJCP sections are listed on the horizontal axis of this figure. A tabular illustration of this figure is also available in Table 6.11. For the first treatment, Joint_Rehab (50.0%) and Thin_OL1 (16.7%) are the most common treatment activities. Thin_OL1 (25.0%), Unbonded_OL (25.0%), and Grind_Seal (25.0%) are the treatment types that have mostly occurred as the second treatment. Reconstruction (40.0%) is the most common treatment in the third order. The treatments that are likely to occur as the fourth treatment are Reconstruction (50.0%) and ReplaceToDJCP (50.0%). And finally, Reconstruction (100%) tend to be used as the fifth treatment on DJCP sections.

By combining the results of the association and sequence analyses with frequency analysis, the treatment strategies embedded in the data set for DJCP sections are revealed as illustrated in Figure 6.12. Treatment types are linked together based on the rules identified during the sequence analysis. The numbers shown in the figure refer to the rule numbers identified in Table 6.10. Some of the rules developed in the sequence analysis are two treatment rules and some of them are three treatment rules. The two treatment rules do not necessarily start from the first treatment. For instance, rules no. 8 and no. 10 indicate a relationship between the second and the third treatments. Other rules such as rule no. 11 and no. 23 indicate a relationship between the first and the third treatments. In addition, the majority of rules belong to the first two treatment activities because pavement sections that have undergone three, four or five treatment activities in their life-cycle are few and these relationships have been filtered out from the results.

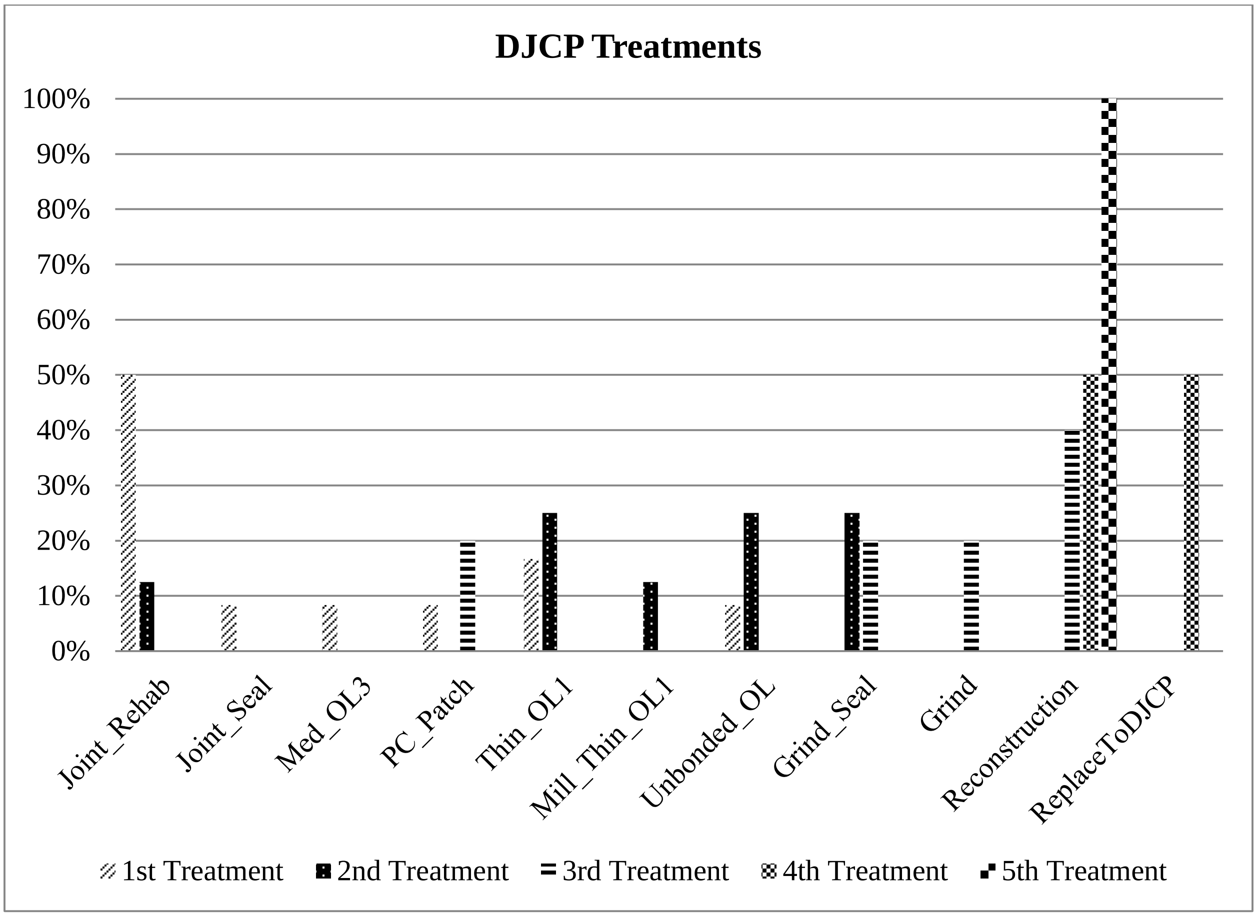


Figure 6.11 Frequency Distributions of DJCP Pavement Treatment Types Based on Time of Occurrence

Table 6.11 Frequency of DJCP Treatment Types

Treatment	1st Treatment		2nd Treatment		3rd Treatment		4th Treatment		5th Treatment	
Joint_Rehab	12	**50.0%**	2	12.5%	0	0.0%	0	0.0%	0	0.0%
Joint_Seal	2	8.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Med_OL3	2	8.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
PC_Patch	2	8.3%	0	0.0%	2	20.0%	0	0.0%	0	0.0%
Thin_OL1	4	**16.7%**	4	**25.0%**	0	0.0%	0	0.0%	0	0.0%
Mill_Thin_OL1	0	0.0%	2	12.5%	0	0.0%	0	0.0%	0	0.0%
Unbonded_OL	2	8.3%	4	**25.0%**	0	0.0%	0	0.0%	0	0.0%
Grind_Seal	0	0.0%	4	**25.0%**	2	20.0%	0	0.0%	0	0.0%
Grind	0	0.0%	0	0.0%	2	20.0%	0	0.0%	0	0.0%
Reconstruction	0	0.0%	0	0.0%	4	**40.0%**	2	**50.0%**	2	**100.0%**
ReplaceToDJCP	0	0.0%	0	0.0%	0	0.0%	2	**50.0%**	0	0.0%
Total	**24**	**100.0%**	**16**	**100.0%**	**10**	**100.0%**	**4**	**100.0%**	**2**	**100.0%**

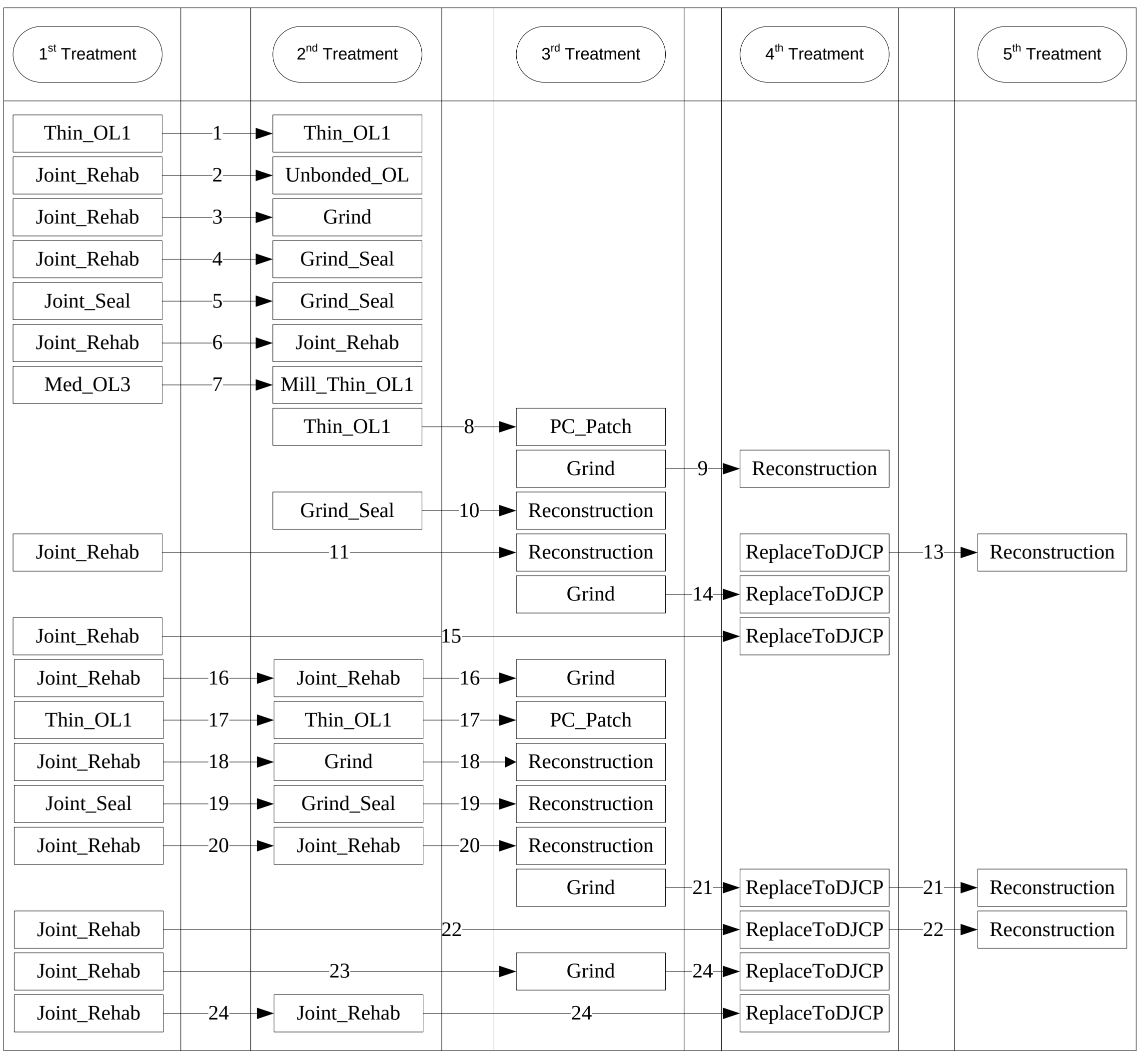


Figure 6.12 Treatment Strategies of DJCP Sections

The data used in the analysis consist of all the DJCP sections of Interstate 40 which have been under very high traffic volume during their life-cycle (i.e. the same pavement family). However, it was found out that many pavement sections that belong to the same pavement family have undergone different treatment strategies during their life-cycles. The results of this analysis indicate that the traditional approach of the SHAs, by assuming one LCC model for each pavement type, needs to be revised.

6.9.4 Realistic LCCA Model

The rules identified in Figure 6.12 are summarized into 12 rules as indicated in Figure 6.13. Only the rules that indicate a relationship between the first three treatment activities are considered in the final LCCA model. Rules such as no. 11 that relates first treatment to the third treatment and rules such as no. 9 that relates the second treatment to the third treatment are ignored. It should be noted that summarizing rules do not mean that these rules are not considered in the model. For instance, rule no. 8 is part of rule no. 17 or rule no. 10 is part of rule no. 19.

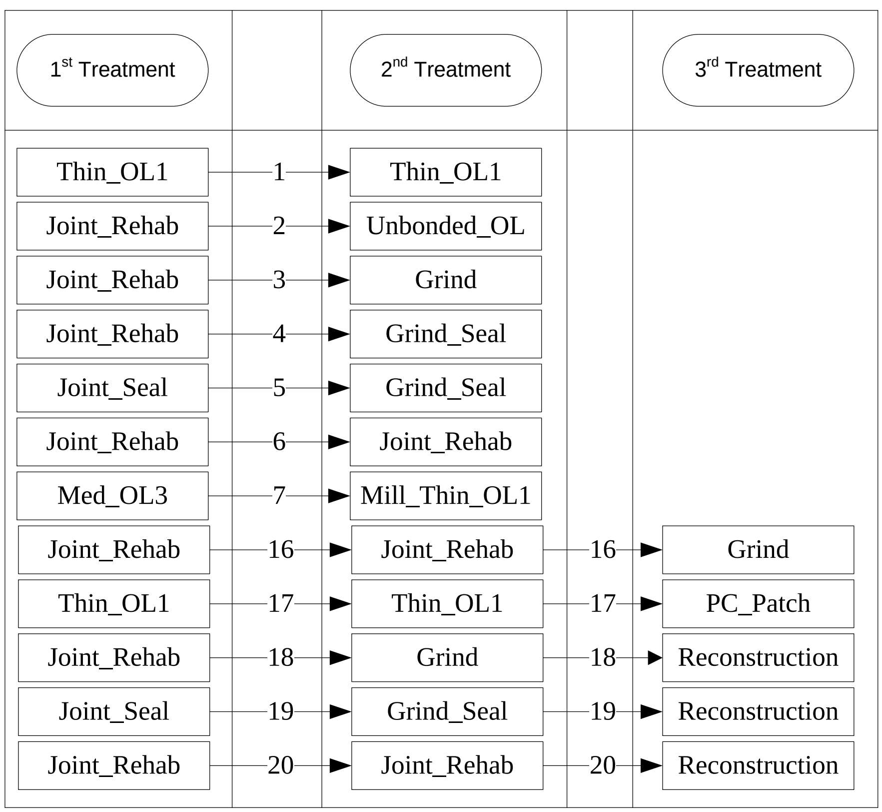


Figure 6.13 Summary of Realistic LCCA Model for DJCP Sections

Realistic LCCA model is based upon the realistic LCC models developed during the association and sequence analyses. In realistic LCCA model, possible treatment strategies are assigned a probability of occurrence, and the final LCC is the weighted summation of individual net present values (NPVs). We are interested in calculating the probability that A and B occur together.

The probability of occurrence is obtained by multiplying the confidence level by the probability of event A. For the rules generated for DJCP sections, Joint_Reahb, Thin_OL1, Joint_Seal, and Med_OL3 are the possible treatment options as the first treatment and their likelihoods of occurrence are 50%, 16.7%, 8.3%, and 8.3% respectively. Therefore the probability of occurrence is calculated by multiplying confidence by the likelihoods of first treatment occurrence for each rule in Figure 6.13. Then these probabilities are normalized in order to have summation of equal to 100%. Probabilities of occurrence can be seen in Table 6.12. Those two treatment rules that are incorporated in three treatment rules are eliminated from the final LCCA model. These rules are no. 1, no. 3, no. 6, no. 5 which are represented by rules no. 9, no. 10, no.8, and no. 11 respectively.

Table 6.12 Final Realistic LCCA Model for DJCP

Rule No.	Rule	Support (%)	Confidence (%)	Probability
8	Joint_Rehab ==> Joint_Rehab ==> Grind	8.33	100.00	25.01%
10	Joint_Rehab ==> Grind ==> Reconstruction	8.33	100.00	25.01%
12	Joint_Rehab ==> Joint_Rehab ==> Reconstruction	8.33	100.00	25.01%
2	Joint_Rehab ==> Unbonded_Overlay	16.67	33.33	8.34%
9	Thin_OL1 ==> Thin_OL1 ==> PC_Patch	8.33	50.00	4.18%
4	Joint_Rehab ==> Grind_Seal	8.33	16.67	4.17%
7	Med_OL3 ==> Mill_Thin_OL1	8.33	100.00	4.15%
11	Joint_Seal ==> Grind_Seal ==> Reconstruction	8.33	100.00	4.15%

The timings of treatment strategies are illustrated in Table 6.13. The average times to the first, the second, and the third treatments are based on the type of treatments and would be different for each strategy. For instance, rule no. 8 starts with Joint_Rehab after 23.2 years of pavement construction. Then it is followed by another Joint_Rehab after 17 years and Grinding after 1 year. Rule no. 10 has started with the same treatment as rule no. 8 but the difference is that Grinding has been performed as the second treatment. This has changed the time to the second treatment to 11 years compared to 17 years in rule no. 8. In treatment strategy no. 9, ODOT has not treated the pavement section for 29 years and then applied Thin_OL1. After two years they are required to apply another Thin_OL1 followed by PC_Patch 13 years later. This is an indicator of the strategies that are dictated due to lack of budget.

Table 6.13 Final Realistic LCCA Model for DJCP

Rule No.	**Rule**	**Time to the 1st Treatment (years)**	**Time to the 2nd Treatment (years)**	**Time to the 3rd Treatment (years)**
8	Joint_Rehab ==> Joint_Rehab ==> Grind	23.20	17.00	1.00
10	Joint_Rehab ==> Grind ==> Reconstruction	23.20	11.00	9.00
12	Joint_Rehab ==> Joint_Rehab ==> Reconstruction	23.20	17.00	9.00
2	Joint_Rehab ==> Unbonded_Overlay	23.20	15.00	-
9	Thin_OL1 ==> Thin_OL1 ==> PC_Patch	29.00	2.00	13.00
4	Joint_Rehab ==> Grind_Seal	23.20	11.00	-
7	Med_OL3 ==> Mill_Thin_OL1	26.00	14.00	-
11	Joint_Seal ==> Grind_Seal ==> Reconstruction	14.00	14.00	10.00
Total		**23.1**	**12.6**	**8.4**

6.10 Realistic LCCA Formulation

The NPV for each strategy is calculated by the formula below:

$$NPV = \sum_{j=1}^{J} P_j = \sum_{j=1}^{J} F_j \left[\frac{1}{(1+i)^{n_j}}\right] \quad \text{Equation 6.6}$$

where;

i = the annual rate of interest

j = the treatment sequence

J = the total number of treatment activities during the analysis period

n_j = the number of interest periods (usually annual)

NPV = the net present value

P_j = the amount at a time assumed to be the present

F_j = the amount n interest periods, hence equal to the compound amount P_j

Then, the realistic LCC is obtained by the following equation:

$$Realistic\ LCC = \sum_{k=1}^{K}((Probability)_k * NPV_k) \qquad \text{Equation 6.7}$$

where;

k = the number of the treatment strategy

K = the total number of possible treatment strategies

NPV_k = the net present value of treatment strategy k, calculated by Equation 5

$(Probability)_k$ = the occurrence probability of treatment strategy k

$$and\ \sum_{k=1}^{K}(Probability)_k = 1 \qquad \text{Equation 6.8}$$

Based on this approach, all the possible treatment strategies affect the final LCC based on their probability of occurrence.

6.11 Summary

In this chapter a novel approach in performing LCCA was introduced and formulated. An intensive data mining analysis was applied on the data set to reveal the typical sequential patterns in the historical pavement treatment projects. Two realistic LCCA models were developed for AC and DJCP sections of Interstate 40. Unlike the deterministic model that assumed each pavement family performs the same and is treated with a single strategy, the realistic LCCA consists of all the possible treatment strategies with different probabilities of occurrence. The results of this novel approach would be closer to actual costs because the uncertainties in adopting treatment strategies have been taken into consideration.

Chapter 7 CASE STUDY

The project selection procedures for alternate bidding as well as the LCC models developed in previous chapters are utilized to conduct a case study. As mentioned earlier, ODOT Roadway Design Division and Field Division evaluate both flexible and rigid pavement designs in terms of a range of factors such as initial construction cost and engineering factors among others. A completed project is selected for further investigation and analysis. The purpose of this analysis is to first determine whether they are a good candidate for alternate pavement type bidding, and then what is the LCC difference between pavement design alternatives.

7.1 Project Information

Project number IM-STIM(001) has been awarded to a contractor in March 2009 and opened to traffic in 2011. The scope of project is 12.83 lane miles full depth reconstruction of I-40 with DJPCC from milepost 281.67 to milepost 288.22. The project is located in Muskogee County on control section 51-15 with annual average daily traffic of 17,500.

During the inception phase, two pavement designs were available for this project which can be summarized to:

1) 11" of DJPCC and 4" cement treated base on top of 8" aggregate base
2) 13" HMA plus 2" SMA plus 1.25" PFC on top of 8" aggregate base.

Figures 7.1 and 7.2 show rigid and flexible pavement designs suggested for this project. The pay items with the unit prices and the initial pavement construction cost analysis can be seen in Table 7.1 for rigid pavement and Table 7.2 for flexible pavement.

Table 7.1 Flexible Surfacing Cost of Project No. IM-STIM(001)

Item	Unit	Total Quantity	Unit Price	Subtotal Price
Fly Ash (12% over 100%)	Ton	16,261	$50.00	$813,050.00
Lime (5% over 35%)	Ton	2,304	$120.00	$276,480.00
Cementitious Stabilized Subgrade	S.Y.	368,582	$1.75	$645,018.50
Lime Stabilized Subgrade	S.Y.	129,410	$2.50	$323,525.00
TBSC Type E	Ton	44,718	$25.00	$1,117,950.00
Aggregate Base	C.Y.	75,207	$29.00	$2,181,003.00
Separator Fabric	S.Y.	368,582	$1.00	$368,582.00
Prime Coat	Gal.	136,863	$1.75	$239,510.25
Tack Coat	Gal.	69,787	$1.50	$104,680.50
HMA S3 (PG 65-22)	Ton	170,130	$70.00	$11,909,100.00
HMA S3 (PG 76-28)	Ton	36,316	$80.00	$2,905,280.00
SMA (PG 76-28)	Ton	23,850	$90.00	$2,146,500.00
PFC	Ton	13,275	$100.00	$1,327,500.00
HMAS4 (OG 64-22)	Ton	8,400	$75.00	$630,000.00
Total				**$24,988,179.25**

Table 7.2 Rigid Surfacing Cost of Project No. IM-STIM(001)

Item	Unit	Total Quantity	Unit Price	Subtotal Price
Fly Ash (12% over 100%)	Ton	16,261	$50.00	$813,050.00
Lime (5% over 35%)	Ton	2,439	$120.00	$292,680.00
Cementitious Stabilized Subgrade	S.Y.	384,165	$1.75	$672,288.75
Lime Stabilized Subgrade	S.Y.	134,153	$2.50	$335,382.50
TBSC Type E	Ton	42,007	$25.00	$1,050,175.00
Aggregate Base	C.Y.	76,562	$29.00	$2,220,298.00
Cement Treated Base	S.Y.	316,411	$9.00	$2,847,699.00
Separator Fabric	S.Y.	400,426	$1.00	$400,426.00
Prime Coat	Gal.	138,218	$1.75	$241,881.50
P.C. Concrete Pavement (Placement)	S.Y.	90,113	$8.00	$720,904.00
Dowel Jointed P.C. Concrete Pavement (Placement)	S.Y.	195,809	$10.00	$1,958,090.00
P.C. Concrete for Pavement (Only)	C.Y.	84,015	$80.00	$6,721,200.00
Total				**$18,274,074.75**

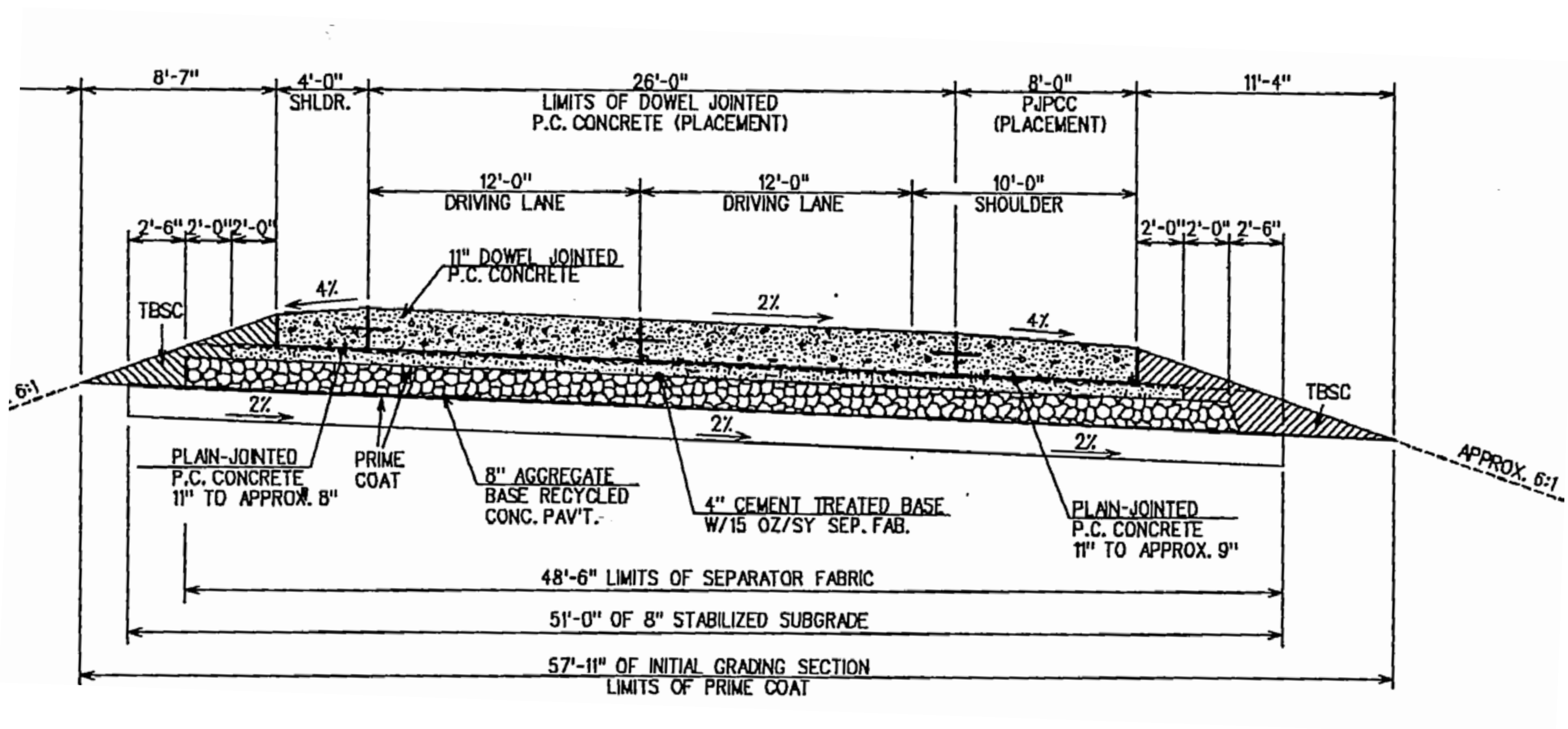


Figure 7.1 Rigid Section of I-40 Pavement Rehabilitation Project (Eastbound)

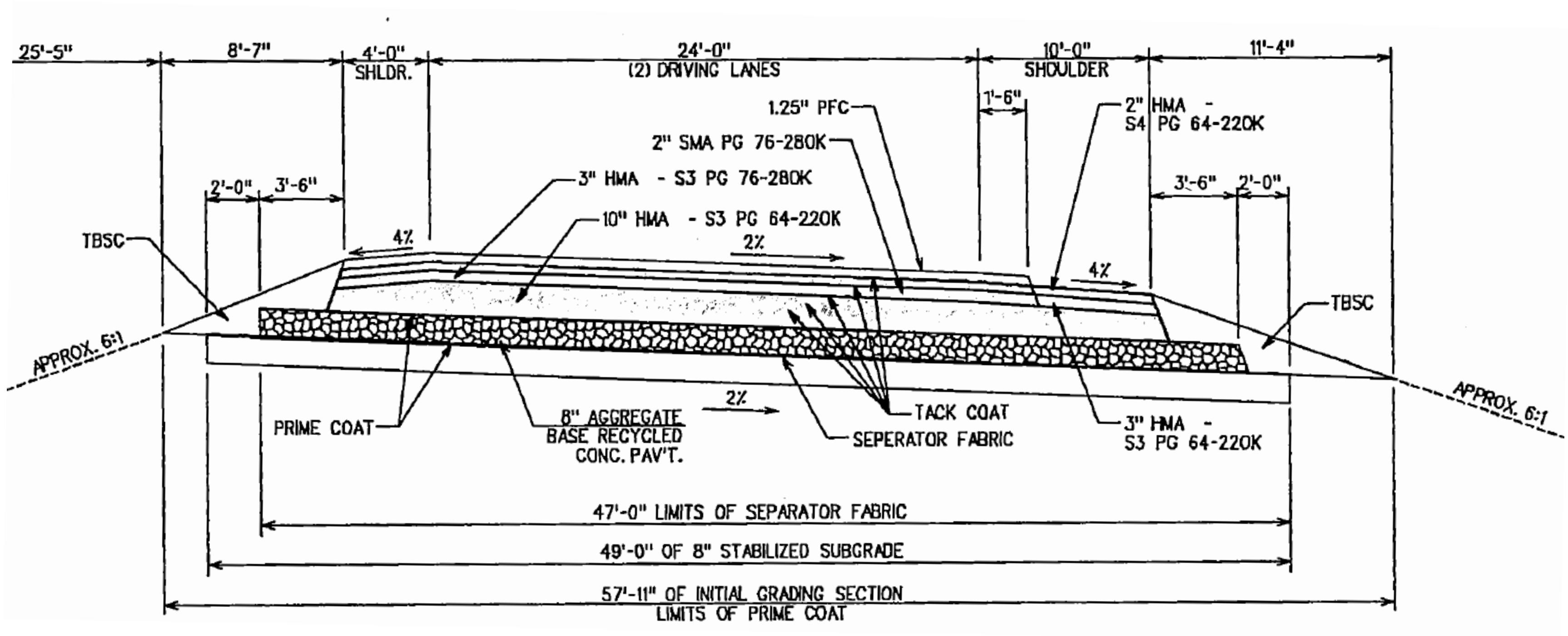


Figure 7.2 Flexible Section of I-40 Pavement Rehabilitation Project (Eastbound)

7.2 Evaluation of Subjective Factors

The surfacing cost of rigid pavement is lower than the surfacing cost of flexible pavement. The difference between initial costs is 27%. According to the alternate bidding project selection procedure developed in chapter 3, if the difference between the initial pavement costs is more than 25%, the alternative with the lower cost would be a better option for the project and selected. Therefore, this project is not ideal for alternate bidding. However, since the difference is only 2% more than the threshold defined in this study, we continue the evaluation. The next step is to check whether pavement costs are more than $7.2 million. In this project, both pavement alternatives are greater than this threshold. Therefore they need to be checked against the next criterion which is whether additional lanes or shoulders are to be added to an existing flexible pavement facility. The existing pavement in this case has been a plain PCC pavement. So LCC should be calculated for both pavement types.

7.3 Life Cycle Cost Analysis

Both deterministic and realistic LCCA models are used in this case study to calculate the LCC of rigid and flexible pavement projects. Table 5.1 determines the deterministic LCCA model developed for flexible and rigid pavement sections of Interstate 40. According to this model, flexible pavement sections are treated two times during their lifecycle. Rigid pavement sections, on the other hand, are treated once before the end of their service life.

7.3.1 Salvage Value

Salvage value represents the value of an investment alternative at the end of the analysis period. This cost is included as negative cost in LCCA. The two fundamental components associated with salvage value are residual value and serviceable life. Residual value refers to the net value obtained from recycling the pavement. The difference between residual values of AC pavement and DJCP sections is generally not very large, and when discounted over 33 years, tends to have little effect on LCCA results. Serviceable life represents the more significant salvage value component and is the remaining life in a pavement alternative at the end of the analysis period. For example, over a 33-year analysis, AC pavement section reaches terminal serviceability at year 33, while DJCP section requires a 6-year design rehabilitation at year 28. In this case, the serviceable life of AC pavement section at year 33 would be 0, as it has reached its terminal serviceability. Conversely, DJCP section receives a 6-year design rehabilitation at year 28 and will have 1 year of serviceable life at year 33, the year the analysis terminates. The value of the serviceable life of DJCP section at year 33 is calculated as a percent of design life remaining at the end of the analysis period (1 of 6 years or 16.67%) multiplied by the cost of DJCP section's rehabilitation at year 33. So the salvage value for pavement alternatives is prorated-based on the cost of final rehabilitation activity, expected life of rehabilitation, and time since last rehabilitation activity as shown below:

$$SV = \left(1 - \frac{L_A}{L_E}\right) C \qquad \text{Equation 7.1}$$

Where

L_E = the expected life of the rehabilitation

L_A = portion of expected life consumed

C = cost of the rehabilitation activity

7.3.2 Deterministic LCCA

A spreadsheet is developed to perform deterministic LCCA. Future costs are discounted to the base year and added to the initial cost to determine the Net Present Value (NPV) for the LCCA alternative. The NPV is the economic indicator and the basic NPV formula for discounting discrete future amounts at various points in time back to same base year is:

$$NPV = Initial\ Cost + \sum_{k=1}^{N} Rehab\ Cost_k \left[\frac{1}{(1+i)^{n_k}}\right] \qquad \text{Equation 7.2}$$

where i = discount rate

n = year of expenditure

Figure 7.3 shows a snapshot of this spreadsheet software. Project information, scope of project, asphalt weight factor, and estimated unit price for material is indicated in this part of the LCCA spreadsheet. Asphalt and OGFC weight factor are required because the unit prices of these items are available in Tons while quantities are estimated based on the geometry of pavement sections in terms of square yard.

	A	B	C	D
1	**Life-Cycle Cost Adjustment Worksheet**			
2				
3	Job Piece No.		20900(05)	
4	Federal Project No.		IM-STIM(001)	
5	County		Muskogee	
6	Route		I-40	
7	Letting Date			
8	Project Length (mi)			
9				
10				
11	Total Area of Paving		286,072.0	SY
12	Area of Traveled Way		195,809.0	SY
13	Area of Shoulders		90,338.7	SY
14				
15	Asphalt Weight Factor		1.97	Tons/CY
16	OGFC Weight Factor		1.97	Tons/CY
17				
18	Analysis Period		33.00	yrs
19				
20	Estimated Unit Price for Asphalt		$70.00	/Ton
21	Estimated Unit Price for Shoulders		$65.00	/Ton
22	Estimated Unit Price for Cold Milling		$2.82	/SY
23	Estimated Unit Price for Diamond Grinding		$2.50	/SY
24				
25	Estimated Unit Price for Open Graded Friction Surface Course		$105.00	/Ton
26	Estimated Unit Price for Fabric Reinforcement		$0.70	/SY
27	Estimated Unit Price for Partial Depth PCC Patching		$125.00	/SY
28	Estimated Unit Price for Sawing		$4.80	/LF
29	Estimated Unit Price for Slab Repair Project		$9.23	/SY
30	Estimated Unit Price for Joint Rehabilitation		$7.10	/SY
31	Estimated Unit Price for Microsurface		$8.52	/SY
32	Estimated Unit Price for Thin_OL1		$18.47	/SY
33	Estimated Unit Price for Mill_Med_OL1		$21.31	/SY
34	Estimated Unit Price for Med_OL1		$21.31	/SY
35	Estimated Unit Price for Mill_Thin_OL1		$13.66	/SY
36	Estimated Unit Price for Grinding		$7.10	/SY
37	Estimated Unit Price for AC Leveling Course		$160.00	/CY
38				
39				
40	Miscellaneous for Asphalt		11.70%	
41	Mobilization for Asphalt		4.60%	
42	Construction added costs for Asphalt		10.10%	
43				
44	Miscellaneous for Concrete		23.00%	
45	Mobilization for Concrete		4.90%	
46	Construction added costs for Concrete		9.60%	

Figure 7.3 Deterministic LCCA Spreadsheet (General Project Information)

The LCC is calculated for both flexible and rigid pavement projects. The deterministic LCC model illustrated in Table 5.1 is utilized to determine the timing and scope of treatment activities. As can be seen in Table 7.3, the averages of OMB real interest rates from 2003 to 2012 are calculated to be used in the LCCA. The average of real interest rates for years 12, 23, and 28 are straight line interpolation from the published rates.

Table 7.3 Average of OMB Real Interest Rates From 2003 to 2012

Year	5-Year	10-Year	12-Year*	20-Year	23-Year*	28-Year*	30-Year +
Real Interest Rate	1.750%	2.300%	2.380%	2.730%	2.760%	2.810%	2.830%

*Straight Line Interpolation From Published Rates

The expenditure stream diagrams for both AC pavement and DJCP sections are shown in Figure 7.4. It is assumed that the AC pavement sections reach the end of their service lives after 33 years and DJCP sections after 34 years. Therefore, the analysis period is assumed to be 33 years in order to facilitate the calculation of salvage values. The salvage value for AC pavement sections is equal to zero while DJCP sections have a salvage value remaining at the end of the analysis period.

Figure 7.5 shows the process of LCCA for AC pavement. As can be seen there are two treatment activities which are performed at years 12 and 23. The treatment activities are based on the LCC models developed in Table 5.1. For each treatment activity, miscellaneous, mobilization, and construction costs are also added to the LCC. The percentages associated with these items are adopted from Missouri DOT LCCA models. These percentages can also be modified by ODOT based on project characteristics and historical information. The thickness of treatment activities are based on the average thickness of treatments in the historical data base. The quantity of material used for the treatment is calculated using the area of paving, area of traveled way, and area of shoulders. For OGFC and AC overlays the weight of material is calculated using the weight factors provided in general information. The unit price of materials is based on the unit prices provided in the general project information section. Cost of material is the product of quantity and unit price. In this case study, the miscellaneous cost is 11.7% of the total treatment costs. Mobilization cost is 4.6% of total treatment costs plus miscellaneous costs. Construction added cost is 10.1% of total treatment costs plus miscellaneous cost plus mobilization cost. Then the cost is discounted using the real interest rate and year of treatment activity. The cost and present worth of both treatment activities are added and reported as total cost and total present worth of AC pavement treatment activities. The equivalent uniform annual cost is calculated using total present worth of the project discounted with the OMB average discount rate and the analysis period of 33 years. The total LCC of AC pavement project is $7,299,879 with the equivalent uniform annual cost of $263,240.

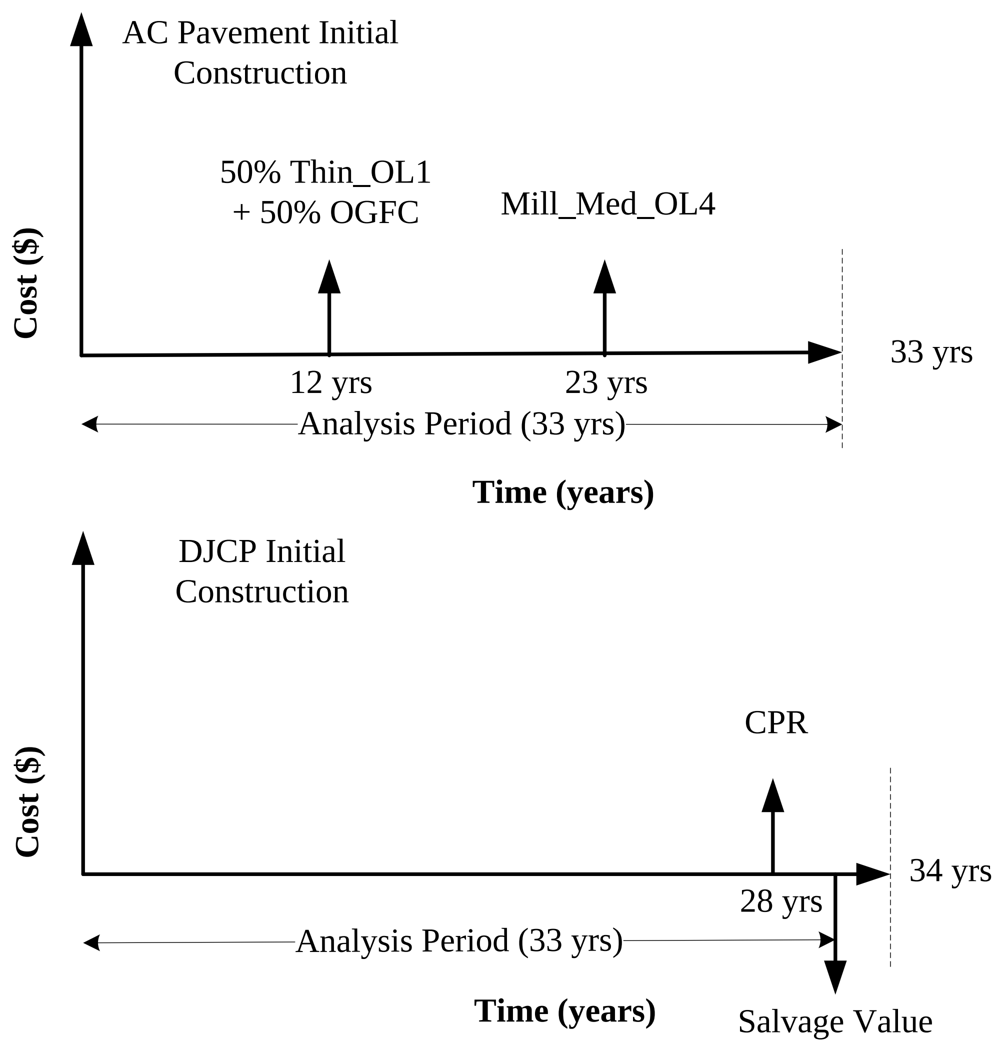


Figure 7.4 Expenditure Stream Diagrams for Deterministic AC Pavement and DJCP Sections LCCA

	A	B	C	D	E	F	G	H	I
1									
2	**ODOT AC Projection**								
3			% or				Unit		Present
4			Thick. (in.)	Year	Quantity	Unit	Price	Cost	Worth
5									
6	**12 Year Maintenance**	12							
7	Discount Rate:	2.380%							
8									
9	Open Graded Friction Course Traveled Way	50.0%	1.25	12	13,394	TON	$105.00	$703,179	$530,254
10	Thin AC Overlay of Traveled Way	50.0%	1.85	12	195,809	SY	$18.47	$1,808,296	$1,363,603
11	Miscellaneous		11.7%	12	1	Price	$293,842.55	$293,843	$221,581
12	Mobilization		4.6%	12	1	Price	$129,044.60	$129,045	$97,310
13	Construction added costs		10.1%	12	1	Price	$296,370.56	$296,371	$223,488
14									
15									
16	**23 Year Maintenance**	23							
17	Discount Rate:	2.760%							
18									
19	Mill and Medium AC Overlay of Traveled Way		4.16	23	195,809	SY	$21.31	$4,172,690	$2,230,806
20	Open Graded Friction Course Traveled Way		1.25	23	13,394	TON	$105.00	$1,406,357	$751,868
21	Fabric Reinforcement	x2		23	391,618	SY	$0.70	$274,133	$146,557
22	Resurfacing Shoulders		1.75	23	18,751	TON	$65.00	$1,218,843	$651,619
23	Miscellaneous		11.7%	23	1	Price	$827,426.66	$827,427	$442,359
24	Mobilization		4.6%	23	1	Price	$363,374.67	$363,375	$194,268
25	Construction added costs		10.1%	23	1	Price	$834,545.24	$834,545	$446,165
26									
27									
28	**Years in analysis:**		**Total Cost:**					**$12,328,102**	**$7,299,879**
29	**33.00**		End of service life	**33**	yrs				
30	Discount Rate:	2.830%							
31			**Equivalent Uniform Annual Cost:**						**$343,252**
32									

Figure 7.5 Deterministic LCCA Spreadsheet for AC Pavement Sections

Figure 7.6 shows the LCCA analysis for DJCP project. According to the deterministic LCC model, only one treatment is applied on the section which is going to be at year 28. The end of serviceability of DJCP sections is one year more than AC pavement sections. Therefore, the LCC of DJCP sections are adjusted for salvage value. The adjusting factor is approximately 97% which is obtained by dividing the entire life of AC pavement sections by the entire life of DJCP sections. The CPR or concrete pavement restoration is a combination of different treatment activities with different weighting factors. Based on the historical pavement treatment data set of Interstate 40, CPR is a combination of 10% Traveled Way Full Depth PCC Patching, 20% Slab Repair of Traveled Way, 30% Joint Rehabilitation of Traveled Way, and 40% Diamond Grinding of Traveled Way. The Miscellaneous, Mobilization, and Construction added cost factors for DJCP sections are assumed to be 23%, 4.9%, and 9.6% accordingly. Using the same equations and procedure as AC pavement sections, the total present worth cost for DJCP project would be $1,906,170 with equivalent uniform annual cost of $89,631.

34	**ODOT DJCP Projection**								
35			% or				Unit		Present
36			Thick. (in.)	Year	Quantity	Unit	Price	Cost	Worth
37	**28 Year Maintenance**	28							
38	Discount Rate:	2.810%							
39	**Treatment**	**Scope**							
40	Traveled Way Full Depth PCC Patching	10.00%		28	19,581	SY	$125.00	$2,447,613	$1,126,556
41	Slab Repair Traveled Way	20.00%		28	39,162	SY	$9.23	$361,463	$166,370
42	Joint Rehabilitation Traveled Way	30.00%		28	58,743	SY	$7.10	$417,073	$191,965
43	Diamond Grinding of Traveled Way	40.00%		28	78,324	SY	$2.50	$195,809	$90,124
44	Miscellaneous		23.0%	28	1	Price	$787,050.36	$787,050	$362,253
45	Mobilization		4.9%	28	1	Price	$206,241.41	$206,241	$94,926
46	Construction added costs		9.6%	28	1	Price	$423,863.99	$423,864	$195,091
47									
48	**Salvage Value**	33							
49	Discount Rate:	2.830%							
50									
51				33			Treatment 1	$806,518.97	-$321,115
52									
53	**Years in analysis:**				**Total Cost:**			**$4,839,114**	**$1,906,170**
54	**33.00**								
55	Discount Rate:	2.830%	End of service life	**34**	yrs				
56			**Equivalent Uniform Annual Cost:**						**$89,631**
57									

Figure 7.6 Deterministic LCCA for DJCP Pavement Sections

Deterministic LCCA Results

The results of the deterministic LCCA analysis indicate that the present worth of treatment costs for AC pavement project would be $5,393,709 more than that of DJCP pavement project. Table 7.4 shows the breakdown of LCCA of both projects. According to the results of LCCA, rigid pavement is clearly the superior pavement type. The rigid pavement is not only $6,715,100 lower in initial cost, but also the present worth of its future treatments is $5,393,709 less than flexible pavement sections. Therefore, the LCC of DJCP for this project is in total $12,108,809 lower than AC pavement. The percentage of difference between these pavement types is 37.5% which is larger than the 13% threshold defined in the alternate bidding project selection procedure. Therefore, this project is not suitable for alternate bidding and the pavement with the lower LCC should be selected.

Table 7.4 Summary of Deterministic LCCA Results for Asphalt and Concrete Pavement Sections

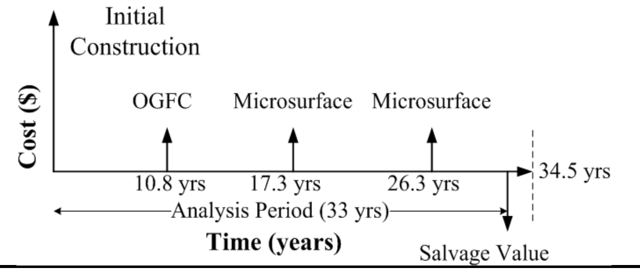
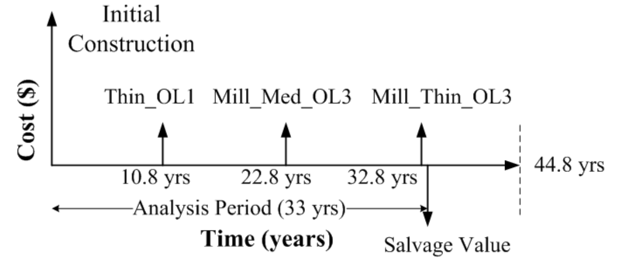
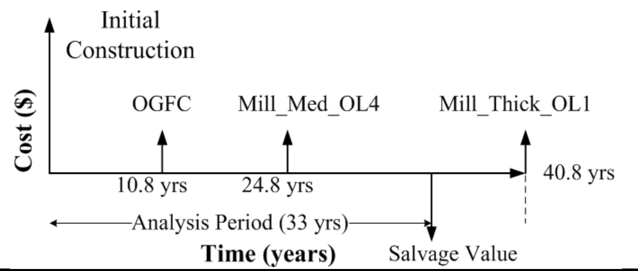
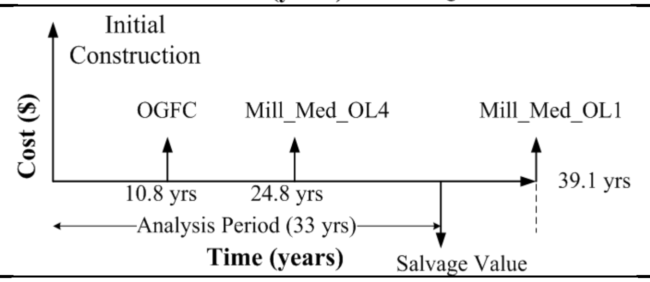
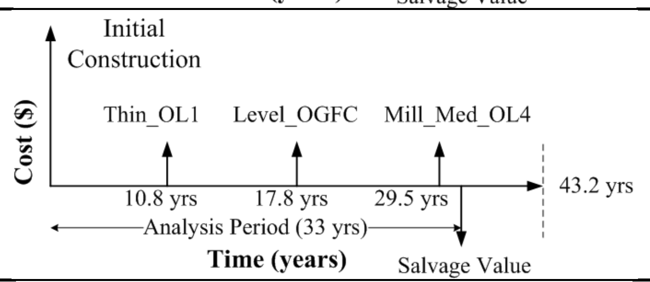
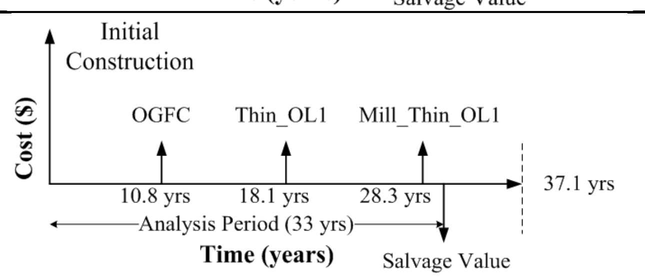
Project	Initial Pavement Cost ($)	Present Worth of Treatment Costs ($)	Total LCCA ($)
AC Pavement	24,989,000	7,299,879	32,288,879
DJCP	18,273,900	1,906,170	20,180,070

7.3.3 Realistic LCCA

The realistic LCCA is based on the models developed for AC pavement and DJCP sections in Chapter 6. Unlike the traditional LCCA, pavement sections are treated with different treatment types with different probabilities of occurrence during their lifecycle. The spreadsheet developed for deterministic LCCA is used for the realistic LCCA tool. The only difference is that instead of determining one LCC for each pavement type, multiple LCC's are developed and weighted average of those costs are considered as the total LCC of that pavement type. Table 6.7 shows the realistic LCCA model for AC pavement sections. The expenditure stream diagrams are developed based on the realistic LCCA models. An Excel-based spreadsheet is developed to calculate LCC for each treatment scenario. The details of calculations can be seen in Appendix E.

Table 7.5 shows the realistic LCCA model for AC pavement sections together with their associated expenditure stream diagrams, probability and net present worth. Each treatment scenario in the model has a unique expenditure stream diagram with different treatment activities, treatment timing, and end of serviceable life. The analysis periods for all the diagrams have been assumed to be 33 years. In all the treatment scenarios, AC pavement sections are treated at least two times during the analysis period which satisfies FHWA recommendations for LCCA. In addition, adopting the same analysis period as the deterministic analysis would enable a better comparison between realistic and deterministic approaches. In the first treatment scenario, all the treatment costs at years 10.8, 17.3, and 26.3 are discounted to the present year. There is remaining service life at the end of analysis period which is calculated by the equation introduced in salvage value section. The last Microsurface applied on the pavement at year 26.3 extends the service life of pavement for 8.2 years. However, the analysis period ends 6.7 years after the treatment activity. Therefore the section has a remaining life of equal to 1.5 years at the end of the analysis period. The salvage value calculations for the second, the fifth, and the sixth scenarios would be the same as the first scenario. In the third and the fourth scenarios, the treatment activities in years 10.8 and 24.8 are discounted to the present time. The third treatment is applied at the end of the service life of pavement. Therefore, this treatment is not considered during the LCCA and the salvage value would be calculated by considering the remaining service life of pavement due to the second treatment activity.

Table 7.5 Realistic LCCA for AC Pavement Sections

No.	Expenditure Stream Diagram	Probability	Present Worth
1		30.94 %	$3,666,254
2		21.21 %	$7,533,845
3		18.56 %	$3,760,930
4		14.85 %	$3,943,578
5		7.96 %	$13,456,222
6		6.48 %	$5,227,307

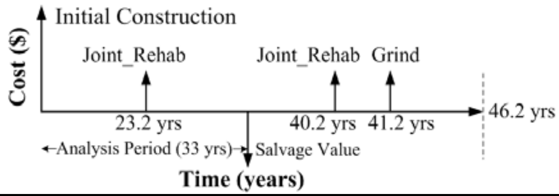
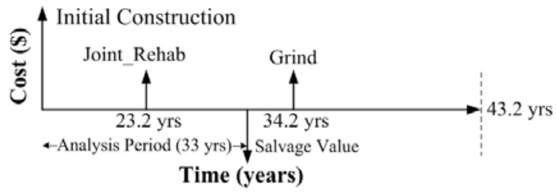
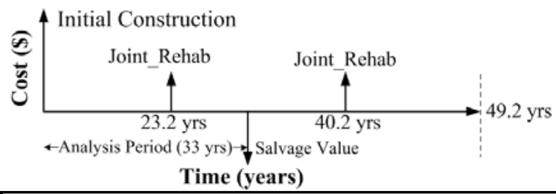
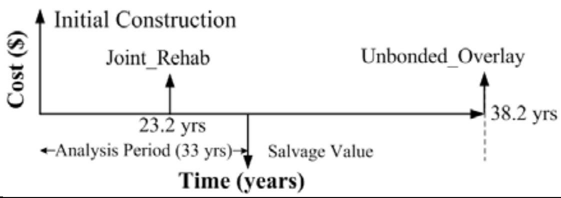
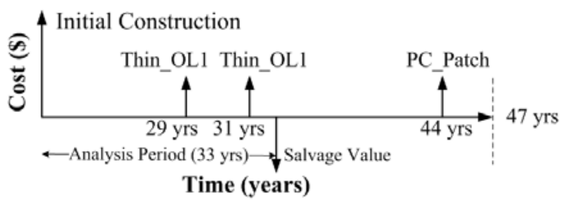
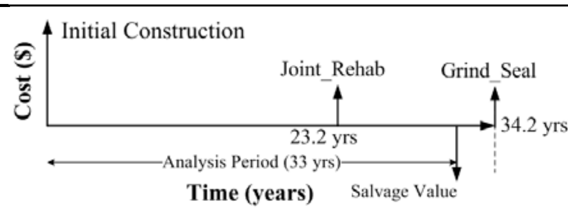
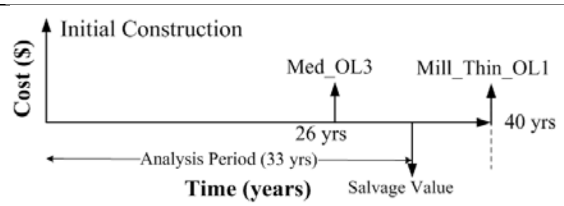
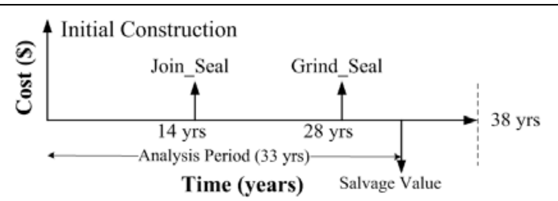
The net present worth for each treatment scenario is multiplied by its associated probability and added together to obtain realistic LCC for AC pavement sections. This process has been illustrated in Table 7.6 which results in realistic LCCA of $5,425,520.29.

Table 7.6 Realistic LCCA Results for AC Pavement

ODOT Realistic AC LCCA				
Rule No.	**Rule**	**Probability**	**Present Worth**	**Probability × Present Worth**
1	OGFC=>Microsurface=>Microsurface	30.94%	3,666,254	1,134,203
2	Thin_OL1=>Mill_Med_OL3=>Mill_Thin_OL3	21.21%	7,533,845	1,598,173
3	OGFC=>Mill_Med_OL4=>Mill_Thick_OL1	18.56%	3,760,930	698,123
4	OGFC=>Mill_Med_OL4=>Mill_Med_OL1	14.85%	3,943,578	585,622
5	Thin_OL1=>Level_OGFC=>Mill_Med_OL4	7.96%	13,456,222	1,070,563
6	OGFC=>Thin_OL1=>Mill_Thin_OL1	6.48%	5,227,307	338,836
Weighted Average Present Worth				**$5,425,520.29**

The realistic LCCA for DJCP sections utilizes the LCCA models developed in previous chapters. A net present worth is calculated for each treatment scenario in the realistic model. A spreadsheet is developed and used to perform the LCCA. Table 7.7 shows the expenditure stream diagrams for possible DJCP section treatment scenario together with their associated probability and net present worth. The realistic LCCA model for DJCP sections consists of eight different treatment scenarios. Each treatment scenario has unique treatment types, treatment timing, service life, and probability of occurrence. The treatment activities within the analysis period are discounted to present year utilizing the average OMB real interest rates. The analysis period for all the scenarios is assumed to be 33 years in order to be consistent and comparable with other analyses in this chapter. All the treatment scenarios have at least one treatment during the analysis period which is in conformance with FHWA recommendations. The salvage value is a negative cost calculated at the end of the analysis period representing the remaining life of pavement section. The salvage value is calculated by determining the remaining service life of the last treatment activity before the end of the analysis period. In the first treatment scenario, Joint_Rehab which is applied in year 23.2 extends the service life of pavement for 17 years. This implies that the remaining service life associated with the treatment at the end of the analysis

Table 7.7 Realistic LCCA for DJCP Sections

<table>
<tr><th>No.</th><th>Expenditure Stream Diagram</th><th>Probability</th><th>Present Worth</th></tr>
<tr><td>1</td><td>
</td><td>25.01 %</td><td>$713,360</td></tr>
<tr><td>2</td><td>
</td><td>25.01 %</td><td>$959,490</td></tr>
<tr><td>3</td><td>
</td><td>25.01 %</td><td>$713,360</td></tr>
<tr><td>4</td><td>
</td><td>8.34 %</td><td>$773,525</td></tr>
<tr><td>5</td><td>
</td><td>4.18 %</td><td>$2,713,338</td></tr>
<tr><td>6</td><td>
</td><td>4.17 %</td><td>$959,490</td></tr>
<tr><td>7</td><td>
</td><td>4.15 %</td><td>$3,022,760</td></tr>
<tr><td>8</td><td>
</td><td>4.15 %</td><td>$1,907,554</td></tr>
</table>

period would be 7.2 years. Using the equation introduced in the salvage value section, a portion of Joint_Rehab cost (7.2 divided by 17) is added as the salvage value. The details of analysis are available in Appendix F.

The final results of realistic LCCA for DJCP sections are illustrated in Table 7.8. The present worth of each treatment scenario is multiplied by the probability of occurrence of that scenario and added together resulting in the realistic LCCA. As can be seen in this table, the present worth of treatment scenarios range from $713,360 to $2,713,338. However, the weighted average of these present values is $1,019,136.47. This would be the realistic LCC for DJCP sections in Interstate 40.

Table 7.8 Final Results of LCCA for DJCP Sections

ODOT Realistic DJCP LCCA				
Rule No.	**Rule**	**Probability**	**Present Worth ($)**	**Probability × Present Worth**
1	Joint_Rehab ==> Joint_Rehab ==> Grind	25.01%	713,360	$178,384.70
2	Joint_Rehab ==> Grind ==> Reconstruction	25.01%	959,490	$239,932.41
3	Joint_Rehab ==> Joint_Rehab ==> Reconstruction	25.01%	713,360	$178,384.70
4	Joint_Rehab ==> Unbonded_Overlay	8.34%	773,525	$64,476.56
5	Thin_OL1 ==> Thin_OL1 ==> PC_Patch	4.18%	2,713,338	$113,310.17
6	Joint_Rehab ==> Grind_Seal	4.17%	959,490	$39,988.73
7	Med_OL3 ==> Mill_Thin_OL1	4.15%	3,022,760	$125,475.91
8	Joint_Seal ==> Grind_Seal ==> Reconstruction	4.15%	1,907,554	$79,183.28
Realistic LCCA				**$1,019,136.47**

Realistic LCCA Results

The results of realistic LCCA indicate that the present worth of treatment costs for AC pavement project would be $5,229,793 more than that of DJCP pavement project. Table 7.9 shows the breakdown of LCCA of both projects. According to the results of LCCA, rigid pavement is clearly the superior pavement type. The rigid pavement is not only $6,715,100 lower in initial construction cost, but also the present worth of its future treatments is $5,229,793 less than flexible pavement sections. Therefore, the LCC of DJCP for this project is in total $11,944,893 lower than AC pavement. The percentage of difference between these pavement types is 39%

which is larger than the 13% threshold defined in the alternate bidding project selection procedure. Therefore, this project is not suitable for alternate bidding and the pavement with the lower total LCC should be selected.

Table 7.9 Summary of Realistic LCCA Results for Asphalt and Concrete Pavement Sections

Project	Initial Pavement Cost ($)	Present Worth of Treatment Costs ($)	Total LCC ($)
AC Pavement	24,989,000	5,425,520	30,414,520
DJCP	18,273,900	1,019,136	19,293,036

7.4 Conclusions

By comparing the results of deterministic and realistic LCCA, it is inferred that realistic approach has resulted in lower LCCs. Table 7.10 shows the results of LCCA for AC pavement and DJCP sections with two different approaches. The realistic LCCA approach has resulted in 26% lower LCC in AC pavement sections and 47% lower LCC in DJCP sections. The difference between LCCs of rigid and flexible pavement sections is 18.3% more in deterministic approach. The difference between LCC of rigid and flexible pavement is the L factor which is used in the alternate bidding process. Figure 7.7 shows the bar chart of LCCA results for deterministic and realistic approaches. Although this case study revealed that this project is not suitable for alternate bidding, the LCC factors were calculated to determine the difference between these two approaches. Figure 7.8 shows the bar chart of LCC factors calculated by two different approaches. The results of this analysis indicate that the realistic LCCA approach can be different from the traditional LCCA. The research team believes that the results of the realistic LCCA approach are closer to the actual costs because all the possible treatment strategies have been considered during the analysis.

Table 7.10 Comparison Between Deterministic and Realistic LCCA Approaches

	Deterministic LCCA	**Realistic LCCA**	**Percentage of Difference**
AC	$7,299,879	$5,425,520	26%
DJCP	$1,906,170	$1,019,136	47%
Difference Between AC and DJCP	5,393,709	4,406,400	18.3%

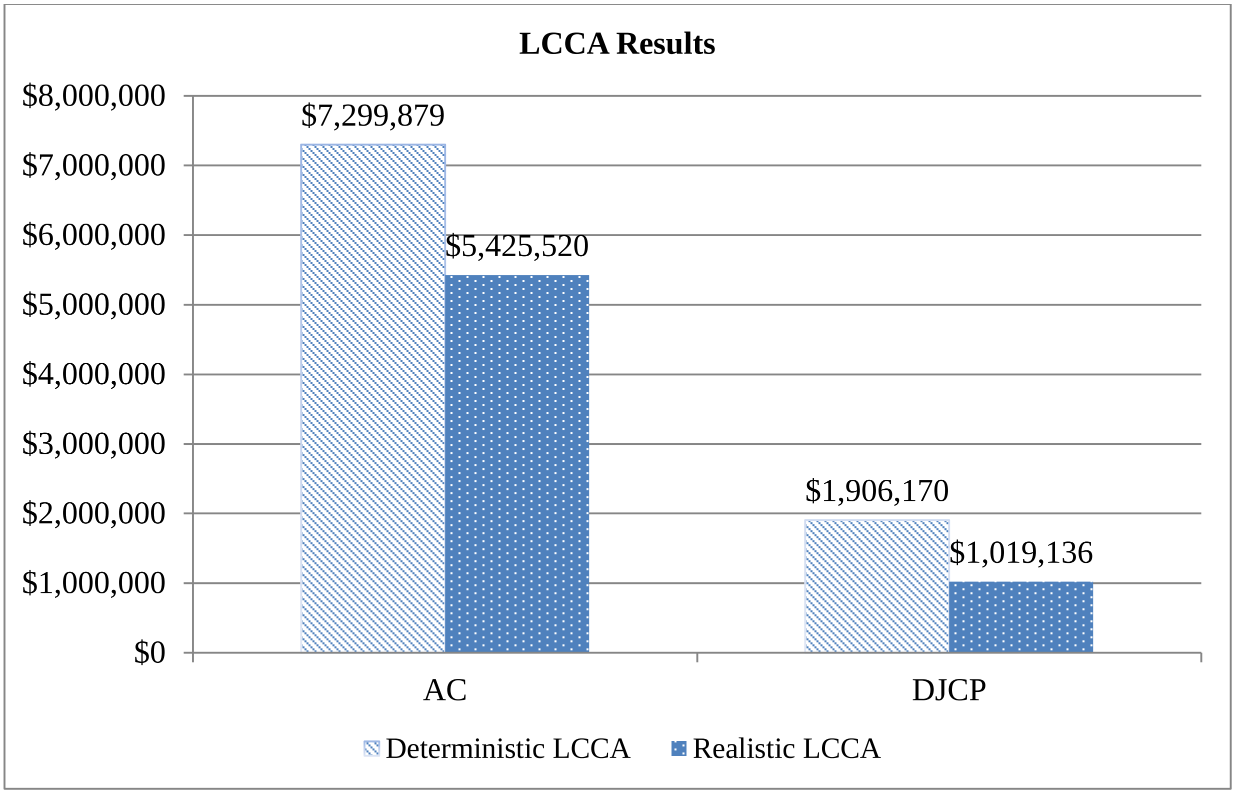


Figure 7.7 The LCCA Results for Deterministic and Realistic Approaches

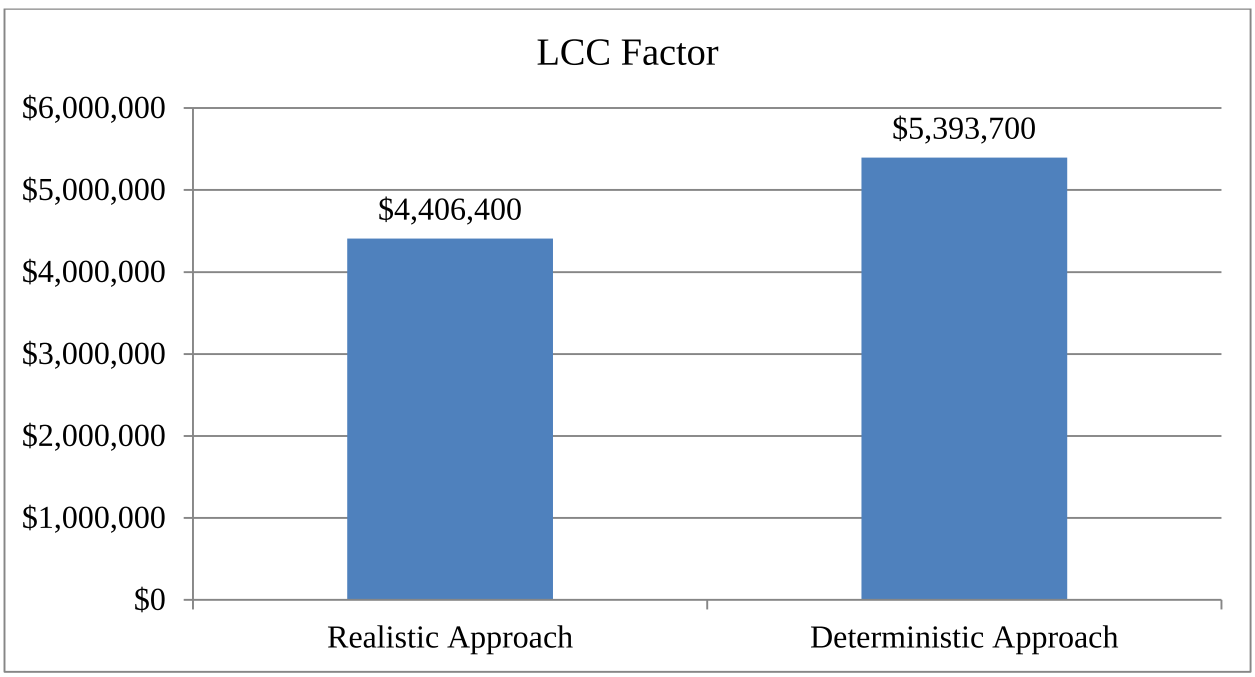


Figure 7.8 LCC Factors for Case Project Based on Realistic and Deterministic Approaches

Chapter 8 RECOMMENDATIONS AND CONCLUSIONS

8.1 Novel Approach in LCCA

This research project introduces a novel approach in performing LCCA by revealing the actual treatment strategies embedded in the historical treatment data sets.

Identifying the sequence of treatment activities is beneficial for several decisions made by SHAs. It assists in developing LCC models for different types of pavement. A realistic LCC model is critically important for pavement type selection or alternate bidding procedures. This enables ODOT to do more with fewer amounts of tax dollars in the long run. By identifying the treatment strategies occurred during the last 50 years, ODOT would be able to plan more efficiently for future maintenance and rehabilitation projects. Contractors may also apply the same methodology on the data collected from their previous performance guarantee contracts in order to forecast pavement treatment activities for the purpose of improving their bid proposals.

The association analysis revealed that several treatment strategies have been applied to single pavement types. Therefore, a realistic LCCA model was developed and compared with the traditional approach where only one treatment strategy was considered in the LCC model. In realistic LCCA model, a probability of occurrence is defined for each treatment strategy, and the final LCC is the weighted summation of individual NPVs. Since LCC models developed in this paper are based on the actual treatment strategies performed by ODOT, it is expected that the LCC is closer to actual costs than that of the traditional approach. Using realistic LCCA models developed in this study helps state DOTs develop more realistic pavement maintenance and rehabilitation strategies and budgets.

Data preparation is one of the main challenges in applying the new process introduced in this study. The historical pavement treatment data are usually collected on a project basis. Therefore, the pavement management datasets need to be restructured in a section based format that association rules mining or sequence analysis can be applied.

The treatmen strategies are what ODOT has actually applied during the last 50 years. While some of these strategies have improved the performance of pavements, some of them have not been applied on the pavements at the right time and sequence. Therefore, the treatment strategies need to be investigated in order to differentiate between the successful sequence of treatments that lead to lowest life-cycle costs and unsuccessful sequences that cause higher life-cycle costs.

8.2 Alternate Bidding Strategies

This project focused on developing alternate bidding procedures for ODOT. Since all projects are not suitable for the alternate bidding process, a decision support framework was developed based on the opinions of Study Advisory Group to determine the significant factors that need to be checked before including projects in alternate bidding. The members of Study Advisory Group are ODOT Construction Division Engineer, ODOT Pavement Management Branch Engineer, ODOT Pavement Design Engineer, FHWA representative, Asphalt and Concrete industry representatives. The ODOT Field Division Engineers were also involved during the questionnaire survey study. Therefore, the research team involved all the stakeholders early in the research process to make sure those different inputs are considered in the process and especially both concrete and asphalt industries have consensus on the alternate bidding procedure. The significant factors based on the questionnaire survey are difference in construction costs of alternatives, the initial pavement costs, existing pavement type, life-cycle cost, vehicle braking actions, AADT of truck traffic, scope of project in terms of lane miles, and local availability of contractors. This framework checks different alternatives of a project against several principal considerations. If no alternative is superior, then the LCCs of alternatives are compared. If the LCCs of alternatives are close enough, then alternative are checked against secondary subjective considerations. If at the end of this process, none of the alternatives are superior, then it means that the alternatives have equivalent designs and the project can be let as alternate bid.

In addition to subjective considerations which have been developed by the questionnaire survey analysis, another aspect of this project is to create an approach for ODOT in order to perform LCCA. The importance of accurate calculation of LCC of pavement type alternatives is two folds. First it results in accurate selection of projects for alternate pavement type bidding. In addition, the LCC factor which is the difference between the LCC of two pavement alternatives would be closer to actual cost which results in selection of a more cost-effective pavement alternative during the bid process.

The historical pavement treatment activities on Interstate 40 were utilized to extract treatment patterns adopted by ODOT. While this data set indicates the actual treatment strategies adopted by ODOT since the construction of Interstate Highways, a review of literature indicated that this data set has not been used for the purpose of developing LCC models. A unique five-step data preparation approach was adopted by the research team to restructure the data set and transform it into a format that is suitable for knowledge discovery and data mining purposes. These steps are transforming data set, breaking control sections, cleaning data set, defining pavement treatment types, and restructuring data set.

Two different approaches were used to create LCC models for different types of pavement: 1) Deterministic and 2) Realistic. In the deterministic approach we used the historical pavement treatment data set of Interstate 40 and developed the LCC model based on statistics such as median and mean. Based on the deterministic model, the treatment activities that occur on each pavement type are the activities that has occurred the most in the data set. Also the time to these activities would be the average of the times that it has taken in the past. Therefore, if different treatment strategies have applied on a pavement family during its lifecycle, the deterministic approach assumes that the strategy that has occurred the most is the LCC of that pavement family. Whereas, realistic approach is based on the significant sequential pavement treatment patterns that are extracted from the data set utilizing a data mining technique called association rules mining. Therefore, the LCC models developed for pavement families consist of different treatment strategies with different probabilities of occurrence associated with them. The research team indicated that the results of these two approaches can be significantly different. The case study analysis indicated that the LCC factor calculated by realistic approach is 3% less than the LCC factor calculated by the deterministic approach.

One challenge SHAs faced while adopting alternate pavement type bidding has been lack of consensus between asphalt and concrete industries in the approach of calculating life-cycle cost adjustment factor. The LCCA models based on historical pavement treatment data set is an unbiased approach that both asphalt and concrete industries can agree on the results. This approach is based on the treatment strategies that have actually occurred during the past.

An Excel-based spreadsheet was created for ODOT to calculate LCC for flexible and rigid pavement alternatives. This spreadsheet enables ODOT to enter project information such as project scope, analysis period, estimated unit prices, miscellaneous, mobilization, and construction added costs for asphalt and concrete pavement projects and obtain deterministic and realistic LCCs of rigid and flexible pavement sections as well as the LCC factor which should be used during the alternate bidding process.

This study has addressed the factors that should be considered prior to and after making the determination to utilize the alternate pavement type bidding procedures specified by FHWA in the memorandum published on November 13, 2008. Table 8.1 shows the factors deemed significant by FHWA and the contributions of this study to each one of them.

8.3 Recommendations

The results of this research project provide ODOT with the basic information required to start the alternate pavement type bidding process. The FHWA has provided SHAs with an opportunity to implement the alternate bidding process under Special Experimental Projects No. 14 (SEP-14). The SEP-14 is a functional experimental program that can be used to evaluate non-traditional contracting techniques. An actual implementation of an alternate pavement type bidding project in ODOT would provide useful information for evaluating the performance of the strategies developed in this study. The following provides recommendations of other state DOTs that have experienced alternate pavement type bidding under FHWA SEP-14 program.

Projects that are selected for alternate bidding should be identified early. The task of preparing plans for alternate bids can also be simplified by the Pavement Design Engineer’s establishment of ground rules for the designing of the alternate pavement projects and making the designs as equivalent as possible in regards to construction and payment [2].

Table 8.1 FHWA Considerations for Alternate Bidding vs. Contributions of This Study

Factors		**Contributions of this study**
The factors that should be considered prior to making the determination to utilize alternate bidding procedures	Designs Must Be Equivalent	This is checked by the alternate pavement type bidding project selection framework. It checks the principal factors, the secondary factors, and the LCC of alternatives. If no alternative is clearly superior, then they are considered equivalent.
	Realistic Discount Rate	As per FHWA recommendations, the discount rates used in this study are average of the real discount rates consistent with OMB Circular A-94 during the past 10 years.
	Consideration of Uncertainty	ODOT would be able to use the Excel-spreadsheet to change the input values and perform a sensitivity analysis for LCCA.
	Realistic Rehabilitation Strategy	The realistic LCCA model considers all the pavement treatment strategies with different probabilities of occurrence.
	Subjective Considerations	These considerations are checked by alternate pavement type bidding project selection framework.
	Appropriate Application	Projects with substantial surface treatment are generally suited for alternate bids.
The factors that should be considered once a decision has been made to bid alternate pavement types	Commodity Price Adjustment Factors	Price adjustment clauses should not be used when using alternate bidding procedures.
	Incentive/Disincentive (I/D) Provisions for Quality	The quality based I/D provisions should provide comparable opportunity for each alternate.
	Specifications of Material Quantities	The results of questionnaire survey (Q.33) indicate that the respondents agree that it would be better to use a single payment method for both types of pavement. ODOT should consider approaches that balance materials quantity risk between the alternate pavement types.
	SEP 14 Approval needed if Using Adjustment Factors	Since LCC adjustment factor is going to be used ODOT, approval under FHWA SEP-14 is required.
	Approval Requirements	When no adjustment factors are used, the division administrator shall review the analysis and concur in the finding of pavement alternate equivalency.

Idaho Transportation Department did a questionnaire survey after they performed their first alternate pavement type bidding. They realized that the lowest bidder and the second lowest bidder have taken proactive steps to be more competitive with their bids. The lowest bidder has studied the future pricing of asphalt, and the second lowest bidder has compared asphalt with concrete in terms of recycled items. This necessitates that the bidding time be adjusted for effective decision making related to the alternate pavement type bidding. In addition, the use of alternate pavement type bidding must be identified up-front so that the plans and documents are fully developed to reflect both alternates. Design engineers should also know that the project is an alternate pavement type bid prior to starting the design since it adds complexity to the design package and requires more time to develop the project documents for each type of pavement in order to convey the proper construction staging, which may differ for each alternative. The length of the projects that are bid as alternate pavement types should be identical [33]. The full list of recommendations of Idaho Transportation Department is available in Appendix F.

Indiana DOT has contacted the asphalt and concrete industry representatives for their comments about the alternate pavement type bidding process. The comments received from the contractors are mostly positive and both industries support the process. The INDOT has also observed that the alternate pavement type bidding has attracted more bidders and competition, obtained true cost savings over similar conventional bid projects, and provided a more competitive market. Some contractors have asked INDOT to publish the LCC adjustment factor before bid opening so they can factor in their bid amount. In the current procedure, the adjustment factor is published just minutes before the bid opening. Therefore, contractors do not have enough time to adjust their bid prices accordingly. Currently, the user costs are not considered in LCCA, however, some contractors have asked for inclusion of current and future lane rental costs in the calculation. The contractors believed that the process is open, transparent, and produces a competitive bid environment [9].

A comparison of the bid costs versus the increased preliminary engineering costs by Michigan DOT indicated that alternate pavement type bidding has resulted in significant initial cost savings; however, the cost effectiveness of the alternate pavement type bidding process cannot be determined until an evaluation can be made of the long-term pavement performance and maintenance costs of alternate bid projects versus those of traditional approach. The Michigan DOT recommends that the Department continue to work with both industries to further improve the process prior to letting any additional alternate bid projects. The MDOT found the involvement of all parties in the development of the Alternate Bidding Process and the partnering efforts between them and the paving industries very critical in the success of the alternate bidding process [6].

A list of recommendations is suggested for the alternate pavement type bidding process in ODOT:

1. The unit costs utilized in this study are the unit costs calculated and used by the ODOT Planning and Research Division. However, for an accurate LCCA the cost of all surfacing actions by pavement type need to be captured over time. It can be a five year average to smooth out the sudden changes in paving costs or changes in materials or processes used.
2. The alternate bidding project selection framework is based on the opinions of SGA and Field Division Engineers. However, the opinion of stakeholders might change or they realize that new principal or secondary factors need to be considered during the pavement type selection process. Therefore, the significant principal and secondary factors in pavement type selection need to be constantly asked from stakeholders and the project selection procedure needs to be updated accordingly.
3. Extra work is required to design plans and compute bid quantities for two pavement types. Therefore, projects that are identified for alternate pavement type bidding should be identified early.
4. Evaluating alternate pavement type bidding requires more evaluations from the contractors as well. Enough time needs to be allocated from the time that bid packages are ready until the bid opening.
5. Pavement design engineers need to know that projects are selected for the alternate bidding process before designing the alternatives.
6. ODOT should consider approaches that balance materials quantity risk between the alternate pavement types. An equivalent system for measurement and payment in alternate bid projects needs to be established. The concrete pavement is paid for by area (square yards), while

asphalt pavement is paid for by weight (tons). This allows an asphalt contractor to bid without concern for quantity overruns in order to meet or exceed the required plan design thickness, while a concrete contractor would have to absorb any extra costs required to ensure avoiding a pay deduction for thickness. Missouri DOT has selected square yards as the method of measurement for both pavement types.

7. The quality based Incentive/Disincentive provisions should provide comparable opportunity for each alternate. Contractors anticipating bonuses for pavement material or smoothness often incorporate this gain into their unit bid price, thus creating a competitive advantage over another contractor less sure of the earning the bonus.
8. Using a single pavement design tool for both asphalt and concrete provides further fair bidding conditions.
9. As more performance and treatment data is gathered for both asphalt and concrete pavement types, the deterministic and realistic LCCA models be adjusted accordingly.
10. The LCCA adjustment factor is added to the low asphalt bid (because it has the higher future costs) for comparison with the low concrete bid. The lower of either of these is awarded the job.

8.4 Recommendations for Future Studies

This project allows ODOT engineers and contractors in Oklahoma to take advantage of the alternate bidding procedures and the Excel-based LCCA spreadsheet when they implement the alternate pavement type bidding. The created project selection procedure assists ODOT to select the right project for alternate bidding. The developed LCCA models provide ODOT with the most realistic prediction of the future treatment activities where both asphalt and concrete industries have consensus on.

The LCCA models in this study have been developed for two pavement families out of 14 available pavement families in ODOT. Since use of alternate pavement type bidding is only allowed in highway reconstruction or rehabilitation projects, only pavement families with high or very high traffic levels are required to be analyzed. In other words, by performing the analysis for 5 additional pavement families, ODOT would be able to develop statewide LCCA models.

A potential improvement area of the process developed in this study is the application of rigorous classification methods to various pavement types. This study is based on the current classification of Pavement families of ODOT. However, with rich pavement performance data available, pavements can be further classified based on other factors such as foundation materials and thicknesses, environmental conditions, and serviceability that may lead to different life cycle performance. This new set of classification of pavements may result in more accurate LCC models by reducing the variability in pavement performance over time.

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REFERENCES

1. Temple, W.H., Z. Zhang, J. Lambert, K. M. Zeringue. Agency process for alternate design and alternate bid of pavements. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1900, Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 122-131.

2. Missouri Department of Transportation (MoDOT). *Pavement Design and Type Selection Process (Phase I report)*, 2004, Missouri Department of Transportation. http://www.modot.org/newsandinfo/documents/MasterPavementReport.pdf. Accessed Aug. 13, 2012.

3. Federal Highway Administration (FHWA). *Clarification of FHWA Policy for Bidding Alternate Pavement Type on the National Highway*. FHWA, U.S. Department of Transportation, November 2008. http://www.fhwa. dot.gov/pavement/081113.cfm. Accessed Aug. 13, 2012.

4. U.S. Government Printing Office (GPO). *Code of Federal Regulations (23 CFR Part 627)*, 2001. http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&rgn=div5&view=text&node=23:1.0.1.7.20&idno=23. Accessed Aug. 13, 2012.

5. Wimsatt, A.J., C. M. Chang-Albitres, P. E. Krugler, T. Scullion, T. J. Freeman, M. B. Valdovinos. *Considerations for Rigid vs. Flexible Pavement Designs When Allowed as Alternate Bids*. Publication FHWA/TX-09/0-6085-1. Texas Transportation Institute, The Texas A&M University System, College Station, Texas, 2009. http://tti.tamu.edu/documents/0-6085-1.pdf. Accessed Aug. 13, 2012.

6. Michigan Department of Transportation (MDOT). *Final Report on the Alternate Bidding of Pavements on the M-6 Southbelt Project*. FHWA, U.S. Department of Transportation, 2001. http://www.fhwa.dot.gov/programadmin/contracts/sep14mi2001.pdf. Accessed Aug. 13, 2012.

7. Smith, T. and R. Fung. Review of Alternate Bid Tenders for Canadian Highway Construction Projects with Life Cycle Cost Component. Presented at Annual Conference

of the Transportation Association of Canada, Charlottetown, Price Edward Island, 2006. http://www.tac-atc.ca/english/resourcecentre/readingroom/conference/conf2006/docs/s018/fung.pdf. Accessed Aug. 13, 2012.

8. Gisi, A.J. *Special Experimental Project (Sep-14) Alternate Surfacing Bidding*. Publication FHWA-KS-09-1. Kansas Department of Transportation, Bureau of Materials and Research, Topeka, Kansas, 2009. http://www.fhwa.dot.gov/programadmin/contracts/sep14_mt2010plan.cfm. Accessed Aug. 13, 2012.

9. Indiana Department of Transportation (INDOT). *Initial Evaluation Report for Special Experimental Project (SEP-14) Alternate Bids on Pavement Type*. Indiana Department of Transportation, Kokomo, Indiana, 2009. http://www.fhwa.dot.gov/programadmin/contracts/sep14in2009eval.cfm. Accessed Aug. 13, 2012.

10. Kentucky Transportation Cabinet (KYTC). *Pavement Type Selection Policy*, Kentucky Transportation Cabinet, 2009. http://transportation.ky.gov/Highway-Design/Pavement%20Design/Appendix%20E.pdf. Accessed Aug. 13, 2012.

11. Newman, G. *Special Experimental Project No.14 (SEP-14) Evaluation of Alternate Pavement Bidding*, Kentucky Transportation Cabinet (KYTC), 2008. http://www.fhwa.dot.gov/programadmin/contracts/sep14kyeval.cfm. Accessed Aug. 13, 2012.

12. Fabrycky, W.J. and B.S. Blanchard. *Life-Cycle Cost and Economic Analysis*. Prentice Hall, Englewood Cliffs, New Jersey, 1991.

13. Anderson, S.D. and J.S. Russell. *Guidelines for warranty, Multi-Parameter, and Best Value Contracting*. Report 451. National Cooperative Highway Research Program (NCHRP), Washington, D.C., 2001. http://www.engr.wisc.edu/cee/faculty/russell_jeffrey/Report_GUIDELINESFORWARRANTy.pdf. Accessed Aug. 13, 2012.

14. Rangaraju, P.R., S. Amirkhanian, and Z. Guven, *Life Cycle Cost Analysis for Pavement Type Selection*. Publication FHWA-SC-08-01, Clemson University and South Carolina Department of Transportation, Clemson, SC, 2008. http://www.clemson.edu/t3s/scdot/pdf/projects/SPR656Final.pdf. Accessed Aug. 13, 2012.

15. American Association of State Highway and Transportation Officials (AASHTO). *An Informational Guide on Project Procedures.* American Association of State Highway Officials, Washington, D.C., 1960.

16. American Association of State Highway and Transportation Officials (AASHTO). *AASHTO Guide for Design of Pavement Structures.* AASHTO, Washington, D.C., 1991.

17. U.S. Government Printing Office (GPO). *Life Cycle Cost Analysis Final Policy Statement*. FHWA, U.S. Department of Transportation, 1996. http://www.gpo.gov/fdsys /pkg/FR-1996-09-18/pdf/96-23870.pdf. Accessed Aug. 13, 2012.

18. Office of Management and Budget (OMB). *Nominal Treasury Interest Rates for Different Maturities*, 2011. http://www.whitehouse.gov/sites/default/files/omb/assets/a94/dischist-2012.pdf. Accessed Aug. 13, 2012.

19. Chen, Z. *Data mining and uncertain reasoning: an integrated approach.* John Wiley & Sons, Inc., New York, 2001.

20. Fayyad, U.M., G. Piatetsky-Shapiro, P. Smyth and R. Uthurusamy. *Advances in Knowledge Discovery and Data Mining.* American Association for Artificial Intelligence (AAAI Press), Menlo Park, California, 1996.

21. Kennedy, R.L., L. Yuchun, B.V. Roy, C.D. Reed and R.P. Lippman. *Solving Data Mining Problems through Pattern Recognition*. Prentice-Hall, Upper Sadle River, NJ, 1997.

22. Zhou, G., L. Wang, D. Wang and S. Reichle. Integration of GIS and Data Mining Technology to Enhance the Pavement Management Decision Making. ASCE Journal of Transportation Engineering, Vol. 136(4), 2010, pp. 332-341. http://ascelibrary.org/doi/pdf /10.1061/%28ASCE%29TE.1943-5436.0000092. Accessed Aug. 13, 2012.

23. Weiss, S.M. and C.A. Kulikowski. *Computer Systems That Learn: Classification and Prediction Methods from Statistics, Neural Networks, Machine Learning, and Expert Systems*. Morgan Kaufmann, San Francisco, California, 1990.

24. Hand, D.J. *Discrimination and Classification*. John Wiley & Sons, Inc., Chickester, U.K., 1981.

25. Kaur, D. and H. Pulugurta. Comparitive analysis of fuzzy decision tree and logistic regression methods for pavement treatment prediction. Journal of WSEAS Transactions Information Science and Application, Vol. 5(6), June 2008, pp. 979-990. http://www.wseas.us/e-library/transactions/information/2008/30-650N.pdf. Accessed Aug. 13, 2012.

26. Amado, V. and K.L.S. Bernhardt. Expanding the Use of Pavement Condition Data through Knowledge Discovery in Databases. Proceedings of ASCE Seventh International Conference on Applications of Advanced Technologies in Transportation (AATT), Cambridge, Massachusetts, 2002, pp. 394-401.

27. Jain, A.K. and R.C. Dubes. *Algorithms for clustering data.* Prentice Hall College Div., Englewood Cliffs, N.J., 1988.

28. Hunter, E. The data mining of New Zealand highway condition data, by data preprocessing and search for Association Rules. Proceedings of The 21st ARRB and 11th REAAA Conference, Transport Our Highway to a Sustainable Future, Cairns, QLD, Australia, 2003, pp. 533-548.

29. Zhang, S.-Y., Y.-L. Ma, and X.-C. Wang. Genesis judgment method of pavement disease by association analysis. Zhongguo Gonglu Xuebao/China Journal of Highway Transport, Vol. 21, 2008, pp. 98-103.

30. Shearer, C. The CRISP-DM Model: The New Blueprint for Data Mining. Journal of Data Warehousing, Vol. 5(4), 2000, pp. 13-22. http://mineracaodedados.files.wordpress.com /2012/04/the-crisp-dm-model-the-new-blueprint-for-data-mining-shearer-colin.pdf. Accessed Aug. 13, 2012.

31. Agrawal, R., T. Imielinski, and A. Swami. Mining association rules between sets of items in large databases. Journal of SIGMOD Rec., Vol. 22(2), 1993, pp. 207-216.

32. Oklahoma Department of Transportation (ODOT). *Pavement Management Policy and Procedures Manual*, in *Internal Report.* Oklahoma Department of Transportation, Pavement Management Branch, 2005.

33. Idaho Transportation Department (ITD). *Initial Report for Innovative Contracting Practices "Alternate Pavement Type Bidding"*.FHWA, U.S. Department of Transportation, 2008. http://www.fhwa.dot.gov/programadmin/contracts/idaho2.pdf. Accessed Aug. 13, 2012.

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APPENDICES

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APPENDIX A

ANALYSIS PERIOD AND REHABILITATION TIMINGS [14]

State DOT	Analysis Period	Time to first rehabilitation		Rehabilitation Service Life	
		Flexible Pavements:	**Rigid Pavements**	**Flexible Pavements:**	**Rigid Pavements**
AL	28 yrs	12 yrs	20 yrs, type not a consideration	8 yrs	8 yrs
CA	Varies, from 20 to 55 years	18-20 yrs Preventive maintenance before	JPCP 20-40 yrs Preventive maintenance before	10 yrs	at least 10 yrs
CO	40 yrs	10 yrs	JPCP, 22 yrs	10 yrs	18 yrs
GA	40 yrs	10 yrs	CRC - 25 yrs JPCP - 20 yrs	10 yrs	20 yrs
IL	40 yrs	Depends on traffic	CPR of JPCP at 20 yrs CRCP. Constructed for high-volume traffic routes and no LCCA is done.	Depends on the traffic factor	20 yrs
IN	40 yrs	25 yrs	JPCP, 30 yrs	15 yrs	12 yrs
KS	30 yrs, but moving to 40 yrs	10 yrs	JPCP, 20 yrs	Approximatel y 10 yrs	7-10 yrs
MD	40 yrs	15 yrs	JPCP, 20 yrs based on a 25-yr initial structural life	12 yrs	Varies depending on which rehabilitation cycle
MI	Depends on the pavement/fix type	26 yrs	JPCP, 26 yrs	10-15 yrs	21 yrs for unbonded overlay, 20 yrs for rubblizing & overlay
MN	50 yrs	For 7 million ESAL or less, route and seal cracks at year 6, for high ESAL do a crack fill at year 7.	JPCP, 17 yrs	Depends on traffic	1st rehab: Joint reseal and minor CPR that lasts 10 yrs 2nd rehab: partial and some full depth repairs to last 13 yrs 3rd rehab major CPR to last 15 yrs (which gives a 33% residual life at the end of the analysis period)
MS	40 yrs	12 yrs	JPCP, 1st rehab @ 16 yrs	9 yrs	16 yrs

State DOT	Analysis Period	Time to first rehabilitation		Rehabilitation Service Life	
		Flexible Pavements:	**Rigid Pavements**	**Flexible Pavements:**	**Rigid Pavements**
MO	45 yrs	20 yrs	25 yrs	13 yrs fro first mill and overlay, 12 yrs for 2nd mill & overlay	20 yrs
MT	35 yrs	19 yrs	JPCP, 20 yrs	12 yrs	20 yrs
NE	50 yrs	15-20	overlay at 35 yrs unless performing exceptional	4" overlay for 12-15 yrs, then additional 4" overlay to give a total life of 50 yrs	15 yrs for a total life of 50 yrs
NC	20 yrs for SN<6.0 and 30 yrs for SN>6.0, looking at 40 yrs for SN>6.0	Typically 12-15 yrs	JPCP, 15 yrs	12 yrs	10 yrs
SC	30 yrs	12 yrs for conventional mixes, 15 yrs for plymer-modified	JPCP, 20 yrs	10 yrs for conventional, 15 yrs for polymer-modified	10 yrs
UT	-	12-15 yrs	JPCP, 10 yrs for minor, 20 yrs for major	OGSC* is 7 to 8 yrs, rest is variable	Varies
VT	-	Varies	20 yrs	10-12 yrs	10-15 yrs
WA	50 yrs	10-17 yrs	JPCP 20-30 yrs	10-17 yrs	Diamond grind 15-20 yrs, DBR** 15 yrs
WI	50 yrs	18 yrs over dense graded bse and 23 yrs over open-graded base	25 yrs (undrained base) if placed over dense graded base and 31 urs if over open-graded based	Mill and overlay to give 12 yrs of service life	8 yrs if the initial rehab is repair 15 yrs if the initial rehab is an HMA overlay
Ontario	50 yrs	19 yrs for dense friction course, 21 yrs for SMA	JPCP, 18 yrs to first rehab, which is minor CPR and diamond grinding	13 yrs, then 12 yrs, then 11 yrs, then 10 yrs	10 yrs

*Dowel Bar Retrofit, **Open Graded Surface Course

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APPENDIX B

QUESTIONNAIRE SURVEY

QUESTIONNAIRE SURVEY

"Selection Criteria for Pavement Project to be Included in Alternate Bidding"

Oklahoma State University is conducting research on developing alternate bidding strategies for asphalt and concrete pavement projects utilizing Life Cycle Cost Analysis (LCCA). Recent changes in pavement materials costs have impacted the competitive environment relative to the determination of the most cost effective pavement structure for a specific project. In response, State Highway Agencies have renewed interest in using alternate pavement type bidding procedures. The Oklahoma Department of Transportation (ODOT) is one of the DOTs that is not utilizing LCCA for their highway projects and does not have alternate bidding strategies for pavement type selection. However, Oklahoma is one of the states that use both rigid and flexible pavements more frequently as compared to the average state in the U.S., which provides a healthy and promising environment to implementing this long-term cost saving approach.

The main goal of this questionnaire survey is to identify significant criteria that must be considered for a project to be included in the alternate bidding. Questions have been developed based on several interviews with ODOT pavement design engineers, comments from the study advisory group, and literature review.

We would like you to participate in this survey and provide us with your valuable opinions. The time required to complete this form is approximately 15 minutes. Please return the completed form by ***May 3, 2011***. You may return the completed survey form in the following ways.

Electronic copy:	Mail:
Please email to david.jeong@okstate.edu or,	David Jeong, PhD.
sabdoll@okstate.edu	Assistant Professor
	207 Engineering South
Fax:405-744-7554	School of Civil and Environmental Engineering
	Oklahoma State University
	Stillwater, OK 74078

Questions have been grouped into ten categories; a) Initial Cost, b) Constructability, c) Project Scope, d) Design, e) Operation, f) Utility Issues, g) Sustainability, h) Traffic, i) Payment Method, and j) Life Cycle Cost Analysis (LCCA). In some questions, the level of agreement to each statement is asked which is based on five-level Likert scale while for other questions, the respondent needs to select a value or a range from the suggested options or specify it. Respondents are encouraged to provide additional factors or subjective considerations for pavement type selection based on their knowledge and expertise at the end of the questionnaire survey.

If you have any questions, please feel free to contact me via email or phone. All data provided for this survey will be considered confidentially. Individual data will not be communicated in any form to another party.

We appreciate your time and support.

David Jeong, Ph.D.
Assistant Professor
207 Engineering South
School of Civil and Environmental Engineering
Oklahoma State University
Stillwater, OK 74078-5033 / Phone: (405) 744-7073

Questionnaire Survey

Selection Criteria for Highway Project to be Included in Alternate Bidding

Indicate your level of agreement with the following statements and answer the questions

Category	No.	Statement					
Initial Cost	**1**	What should be the minimal percentage of difference in construction costs between two alternates in order for them to be considered in alternate pavement bidding?	**1-5%** ☐	**5.1-10%** ☐	**10.1-15%** ☐	**15.1-20%** ☐	**20.1-25%** ☐
	2	In order to use alternate designs in a project, the minimum project cost should be more than a certain amount.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	3	In order to use alternate designs in a project, the minimum project cost should be more than	**$5 mil** ☐	**$10 mil** ☐	**$15 mil** ☐	**$20 mil** ☐	**Or Specify:**
Constructability	**4**	Alternate designs should not be considered where the proposed pavement structure matches the adjoining section.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	5	For construction projects along a roadway that will be built in sections (i.e., in separate construction projects), the pavement type for the first project should be used for all future projects on the roadway.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	6	Completion time of project should be considered as a significant factor in the pavement type selection process.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
Project Scope	**7**	Local availability of contractors from both concrete and asphalt industries affects the decision of including alternate pavement designs.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	8	Concrete pavement is not considered practical where additional lanes or shoulders are to be added to an existing flexible pavement facility.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	9	Project length is a significant factor in deciding whether or not to include alternate pavements in a project.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	10	A minimum number of lane miles that could be a requirement for considering pavement alternates should be close to	**2 lane miles** ☐	**3 lane miles** ☐	**4 lane miles** ☐	**5 lane miles** ☐	**Or Specify:**
	11	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.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐

Project Scope	11-1	If you agree with statement # 11, the minimal project size in order to be considered large enough should be	2 lane miles ☐	3 lane miles ☐	4 lane miles ☐	5 lane miles ☐	Or Specify:
	12	Pavement alternates should not be considered where a project has a projected cumulative 18-kip equivalent single axle load (ESAL) value of at least 15 million over 20 years.	*Strongly Agree* ☐	*Agree* ☐	*Not Sure* ☐	*Disagree* ☐	*Strongly Disagree* ☐
	13	Rigid pavements should be used if there are subgrade issues that cannot be effectively addressed during initial construction.	*Strongly Agree* ☐	*Agree* ☐	*Not Sure* ☐	*Disagree* ☐	*Strongly Disagree* ☐
	14	It is not considered practical to place concrete pavement on rural farm to market roads.	*Strongly Agree* ☐	*Agree* ☐	*Not Sure* ☐	*Disagree* ☐	*Strongly Disagree* ☐
	15	Local availability of material affects pavement type selection process.	*Strongly Agree* ☐	*Agree* ☐	*Not Sure* ☐	*Disagree* ☐	*Strongly Disagree* ☐
	16	Project priority and the necessity of a fast turnaround may affect pavement type selection.	*Strongly Agree* ☐	*Agree* ☐	*Not Sure* ☐	*Disagree* ☐	*Strongly Disagree* ☐
	17	Projects with substantial bridge or earthwork items are generally not suited for alternate bids.	*Strongly Agree* ☐	*Agree* ☐	*Not Sure* ☐	*Disagree* ☐	*Strongly Disagree* ☐
Design	18	For projects where the spacing between bridges is around a half mile, it may not be practical to use flexible pavements.	*Strongly Agree* ☐	*Agree* ☐	*Not Sure* ☐	*Disagree* ☐	*Strongly Disagree* ☐
	19	Hydrological issues may be a concern on some projects if the thickness difference between the alternates is significant.	*Strongly Agree* ☐	*Agree* ☐	*Not Sure* ☐	*Disagree* ☐	*Strongly Disagree* ☐
	20	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 controls, would obviously be affected as well. What is your estimate of more time for designers to develop PS&E for pavement alternate projects?	Less than 10% ☐	10-30% ☐	30-60% ☐	60-90% ☐	90-100% ☐
	21	Alternate pavement designs need to be designed for the service performance of	20 years ☐	30 years ☐	40 years ☐	50 years ☐	Or specify:

Design	22	Flexible pavement sections tend to be significantly thicker than rigid pavements when high truck traffic is projected.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	23	Sub grade condition must be verified prior to the design of either pavement type.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
Operation	24	Rigid pavements should be placed where significant vehicle braking actions occur, such as at intersections and ramps.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	25	For flexible pavement design, the divisions should be allowed to vary the minimum time to first overlay depending on their experience and conditions.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
Utility Issues	26	Pavement alternates should not be considered in urban areas where sewer and water lines exist. In other words, concrete pavement is not suggested if there are utility maintenance issues that would require the pavement structure to be removed.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
Sustainability	27	In the pavement type selection process, priority should be given to a pavement type that facilitates the recycling more efficiently.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	28	In the pavement type selection process, priority should be given to a pavement type that produces less Greenhouse gas emissions during production and installation process.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	29	In the pavement type selection process, priority should be given to a pavement type that absorbs less heat in order to reduce temperature in hot urban areas.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
	30	Asphalt pavement surfaces create lower level of tire/pavement noise compared to concrete pavement.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
Traffic	31	User delays need to be incorporated in LCCA for alternate pavement type bidding.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐

Traffic	**32**	Heavy truck traffic is called to a situation where percentage of truck traffic in highways is in the following range.	***10 - 15%*** ☐	***15-20%*** ☐	***20-25%*** ☐	***25-30%*** ☐	***30% or more*** ☐
Payment Method	**33**	For asphalt; contractors are paid based on the tonnage of material delivered to the construction site while for concrete; the payments are based on the volume of pavement as per the design. This may create bias towards asphalt pavement especially when design has underestimated the required concrete volume. To facilitate a fair environment for competition, it would be better to use a single payment method for both types of pavement.	***Strongly Agree*** ☐	***Agree*** ☐	***Not Sure*** ☐	***Disagree*** ☐	***Strongly Disagree*** ☐
LCCA	**34**	What should be the percentage of difference in the total LCCs between two alternates in order for them to be considered close enough for alternate pavement bidding?	***10%*** ☐	***15%*** ☐	***20%*** ☐	***25%*** ☐	***Or specify:***
	35	What should be the analysis period for Life Cycle Cost Analysis (LCCA) in order to reflect long-term cost differences associated with pavement alternate designs?	***30 yrs*** ☐	***35 yrs*** ☐	***40 yrs*** ☐	***45 yrs*** ☐	***Or specify:***

What are the other significant factors that you consider would be important to be included when a pavement project needs to selected for alternate bidding? **Please rank your answers based on their level of importance.**

1) ______________________________

2) ______________________________

3) ______________________________

4) ______________________________

5) ______________________________

6) ______________________________

Thank you for your participation and support!

APPENDIX C

LOG CARD OF CONTROL SECTION 56-03 IN INTERSTATE 40

FORM RL-3
Revised 1956

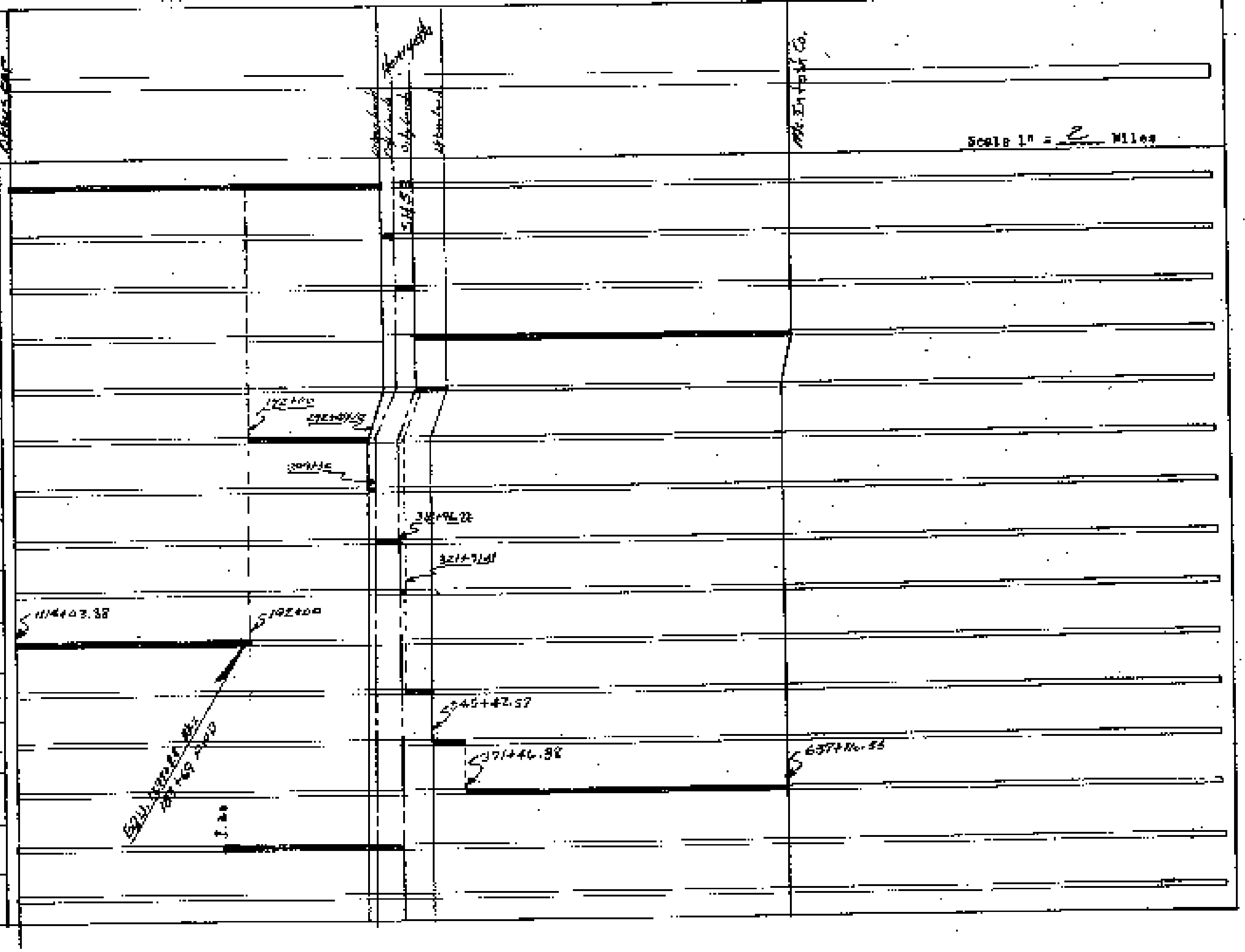
STATE OF OKLAHOMA
DEPARTMENT OF HIGHWAYS
DEPARTMENT OF STATISTICS
U.S. BUREAU OF PUBLIC ROADS

Sheet 1 of 1
Control Section Okmulgee Co. #56
40-56-03

ROAD LIFE STUDY CONSTRUCTION PROJECT LOG

Location and Termini
Fr: Okfuskee County Line
East
To: McIntosh County Line

RL-1 Card No.	Date Comp.	Proj	Type of work	Width	Thick. Surf. / Base	Miles
188			Projected		—	5.800
227			Projected			0.200
228			Projected			0.300
229			Projected			6.900
245			Projected			0.500
246	12/64	I-40 6(90) 256	P.C. Conc.	48'	9 / —	1.903
247	12/64	I-40 6(90) 256	P.C. Conc.	48'	9 / —	0.129
248	12/64	I-40 6(90) 256	P.C. Conc.	48'	9 / —	0.372
249	12/64	I-40 4(94) 236	P.C. Conc.	48	9 / —	0.056
250	/65	I-40 4(49) 232	P.C. Conc.	48'	9" / —	3.639
251	/65	I-40 4(94) 232	P.C. Conc.	48'	9" / —	0.444
252	/65	I-40 8(79) 233	P.C. Conc.	48'	9" / —	0.494
253	/65	I-40 4(48) 239	P.C. Conc.	48'	9" / —	5.045
[illegible]	[illegible]	[illegible]	1½" Asph. Conc. Pres. ...	48	1 / 6	2.84



CONSTRUCTION LOG

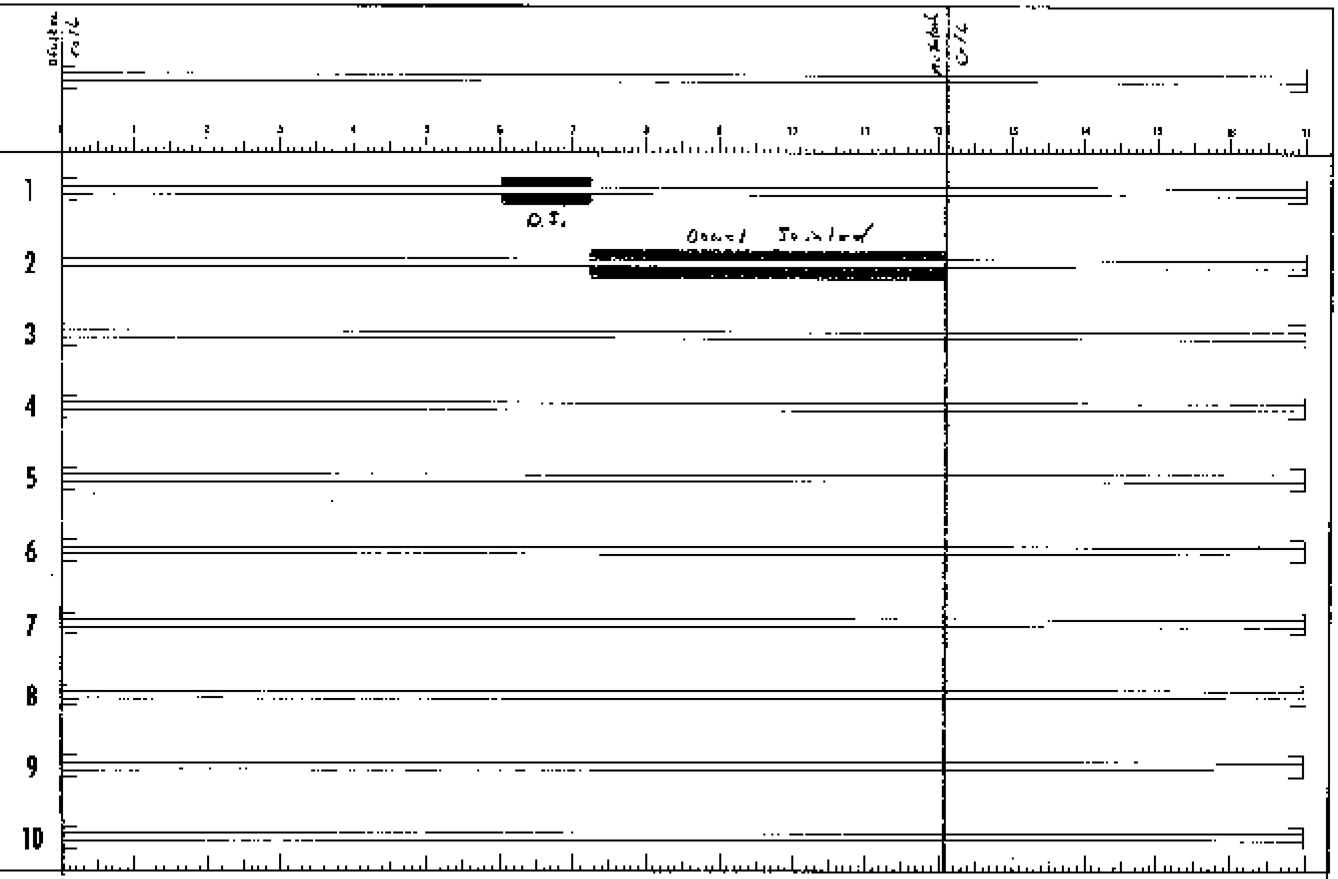
ROAD LIFE AND INVESTMENT STUDY

STATE OF OKLAHOMA
DEPARTMENT OF HIGHWAYS
PLANNING DIVISION

COUNTY Okmulgee
CONTROL SECTION 40-56-03
SHEET 2 OF 2

LOCATION AND TERMINI
FROM Okfuskee County Line
TO McIntosh County Line

YEAR BUILT	CONTRACT NUMBER	WIDTH	THICKNESS SURF.	THICKNESS BASE	TYPE OF WORK	LENGTH
06 27 00	JMY-40-6 (216) 290	48	10"	3	10" RC Concrete over 3" Type "B" over 6" Aggr base over 6" ...	1.24
06 27 00	JMY-40-6 (216) 290	48	10"	3	10" RC Concrete over 3" Type B over 9" existing R.C. over 6" ... Soil ...	4.80



REMARKS

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APPENDIX D

ODOT BREAK REASONS FOR CONTROL SECTIONS

Break Reason: (Column Name: BREAK_REASON)

- Code this item to indicate the reason a subsection break is necessary. When more than one reason occurs at the same time; use the lowest numbered reason. When making subsection breaks for ramps / interchanges see page 24 for more information.

  Roadway Codes:
  1) State Highway Junction #1
  2) Enter Municipal Limits #2
  3) Leave Municipal Limits #2
  4) Enter Urban Area Boundary #2
  5) Leave Urban Area Boundary #2
  6) Surface width, or Type Change #3
  7) Shoulder width, or Type Change
  8) N.H.S. Change
  9) Other
  10) Terrain Area Type
  11) Begin Control Section at County or State Line
  12) Centroid Break Point only
  13) HPMS Break
  14) Maintenance Division Break
  15) Project Break
  16) Enter Oklahoma Test Section
  17) Leave Oklahoma Test Section
  18) Last Maintenance Date
  19) Maintenance Responsibility
  20) Junction of Proposed Highway or Old Highway
  21) Under Construction or Improvement Type change
  22) Programming Break, on 8.00 Mile Contract Length Project

  Interchange Codes:
  23) Diamond 1-side
  24) Trumpet 3-leg
  25) Fully Directional 3-leg
  26) Modified Cloverleaf with Collector
  27) Modified Trumpet
  28) Full Cloverleaf
  29) Full Diamond
  30) Full Diamond 1-Quadrant Cloverleaf
  31) Half Diamond
  32) 3-Leg Directional Loop
  33) 3-Leg Directional
  34) 2-Quadrant Cloverleaf
  35) Modified Diamond
  36) No Interchange Involved

(See pages 13, 26, and 74 for additional Break Reason Notes)

Break Reason Notes **(Continued from previous page)**

- Junctions with another RFC control section.
- Junctions with a State Highway.
- Junctions with County Commissioner Districts (Mileage is split between district boundaries).
- See UFC or RFC control section books for junction break point criteria, and coding direction.
- Municipal and urban limits are defined as the point at which the limits occur on both sides of the roadway facility.
- On **open type sections** a surface width break shall be made when the normal width of the section changes 2 feet or more. On **curbed sections** when the curb-to-curb width changes by 1 foot or more. The **break point** for changing from 2 to 4 lanes, 4 to 6 lanes, etc, shall be where the standard construction of the greater lanes section width begins or ends. The transition areas will be included in the subsection with the lessor number of lanes.
- Surface type breaks will be made where the exposed surface type of the inventory changes.
- Do not break subsections for surface type or width change at channelized intersections, transitions from 2 to 4 lanes, or maintenance improvements to correct base failures or alignment problems unless the length is over 0.50 mile long.
- Do not break surface type or width subsections for short extents of short sections of standard construction at bridge locations, intersection improvements, or alignment correction where the construction design meet Oklahoma design standard; i.e. 24' surface with paved shoulders.

Subsection Length: (Column Name: LENGTH_3D_MI)

- Record the length of the inventoried subsection to the nearest hundredth **(00.01)** mile. For divided roadway subsection, the subsection length for both sides will be the same.

Number of Lanes: (Column Name: NO_LANES)

- Code the number of through traffic lanes for the type of facility:
  0 -Zero One Lane, One-Way Facility (Ramp & Frontage Roads Only)
  1 Two Lanes, One-Way Facility (Ramp & Frontage Roads Only)
  2 Two or Three Lanes Two-Way Facility
  3 Two or Three Lanes One-Way Facility (City One-Way Pairs Only)
  4 Four Lane Facility
  6 Six Lane Facility
  8 Eight Lane Facility
- Do not include acceleration / deceleration lanes, exit only, merging, climbing, left or right turn only lanes. Lanes should be stripped off or otherwise evident on the roadway surface.
- For **multilane sections** enter the **total** number of lanes for **both sides.**

Surface Type:

(Column Names: SURFACE_TYPE_CD, SURF_PRIMARY, SURF_ORIGINAL, BASE_TYPE, SURF_THICKNESS)

- **(See the Base and Surface Chart on page 27)**

Surface Width: (Column Name: SURFACE_WIDTH)

- Record the width of through lane driving surface from inside shoulder to inside shoulder or face to face of curb. **Do not include** medians, turn lanes or climbing lanes. For **open type sections** record the width to the nearest even foot (18, 20, 22, 24). For **2 lane facilities** do not exceed 24 feet. Any excess surface over 24 feet shall be included in shoulder width.

“Rules of the Road”

I. Additional Guidance for Break Reasons
- Always break for a new subsection when the inventory route crosses or changes:
  - State or U.S. numbered highway with a grade crossing.
  - Major or minor collector.
  - County Commissioner district boundaries.
  - Municipal limits.
  - Urban Area Boundaries.
  - Change in reservation (Col. 33), i.e. State Parks, National Forests, Indian Agencies, etc.
  - Number of lanes.
  - Surface width.
  - Surface type.
  - Right-of-way width.

II. Split Mileages
- When an inventory route lies along the boundary of either the county itself or the county commissioner districts, it is necessary to split the mileage between both administrative units. If the boundary is a county commissioner district, record one-half in one district and the other half in the adjacent district. Do code the road as one continuous piece, i.e., do not make the second entries subsection **0000.** If the boundary is a county line, code the entire subsection as one-half of its actual length. The other half will be posted in the adjacent county’s file, so do not be concerned with it. The exception to split mileages is State line roads. Record these roads in the normal manner.

III. City Codes
- Remember to record the appropriate city code when a road goes inside **EITHER** municipal limits **OR** an Urban Area.
- If the road is in an urban area but not in the city limits, Rural / Municipal code will be **1** AND the Population Group code will be **0** but **the City code cannot be 00.**

IV. County Line Collectors
- Before coding a county, be sure to check the surrounding county’s collector map for any collectors. This avoids duplication of mileage.

V. Local City Streets
- When coding local city streets, first label all municipal county roads and collectors (or **F.A.U.’s** in Urban Areas). Also note the alignments of any highways. The above is necessary to avoid duplication of mileage. Do not color the collectors (or F.A.U.’s),since this may lead to confusion with city streets that are Portland Cement.

- Instead, label the route by its respective number and place arrows on its termini, if applicable. Remember that city street mileages are cumulative, so there should be relatively few entries in most city’s files.

APPENDIX E

REALISTIC LCCA FOR AC PAVEMENT

O7

	A	B	C	D	E	F	G	H	I	J
1										
2	**ODOT AC Projection (#1)**									
3			% or					Unit		Present
4			Thick. (in.)	Year	Adjustment	Quantity	Unit	Price	Cost	Worth
5										
6	**10.8 Year Maintenance**	10.8								
7	Discount Rate:	2.330%								
8										
9	Open Graded Friction Course Traveled Way		1.25	10.8		13,394	TON	$105.00	$1,406,357	$1,096,639
10	Miscellaneous		11.7%	10.8		1	Price	$164,543.81	$164,544	$128,307
11	Mobilization		4.6%	10.8		1	Price	$72,261.45	$72,261	$56,347
12	Construction added costs		10.1%	10.8		1	Price	$165,959.42	$165,959	$129,411
13										
14										
15	**17.3 Year Maintenance**	17.3								
16	Discount Rate:	2.620%								
17										
18	Microsurface		1	17.3		195,809	SY	$8.52	$1,668,293	$1,066,494
19	Miscellaneous		11.7%	17.3		1	Price	$195,190.24	$195,190	$124,780
20	Mobilization		4.6%	17.3		1	Price	$85,720.21	$85,720	$54,799
21	Construction added costs		10.1%	17.3		1	Price	$196,869.52	$196,870	$125,853
22										
23	**26.3 Year Maintenance**	26.3								
24	Discount Rate:	2.793%								
25										
26	Microsurface		1	26.3		195,809	SY	$8.52	$1,668,293	$808,409
27	Miscellaneous		11.7%	26.3		1	Price	$195,190.24	$195,190	$94,584
28	Mobilization		4.6%	26.3		1	Price	$85,720.21	$85,720	$41,538
29	Construction added costs		10.1%	26.3		1	Price	$196,869.52	$196,870	$95,398
30										
31	**Salvage Value**	33								
32	Discount Rate:	2.830%								
33										
34				33				Treatment 3	$392,574.27	-$156,303
35										
36										
37										
38										
39	**Years in analysis:**		**Total Cost:**						**$6,493,842**	**$3,666,254**
40	**33**		End of service life	**34.5**	yrs					
41	Discount Rate:	2.830%								
42			**Equivalent Uniform Annual Cost:**							**$172,393**
43										

M20 | f_x

	A	B	C	D	E	F	G	H	I	J
1										
2	**ODOT AC Projection (#2)**									
3			% or					Unit		Present
4			Thick. (in.)	Year	Adjustment	Quantity	Unit	Price	Cost	Worth
5										
6	**10.8 Year Maintenance**	10.8								
7	Discount Rate:	2.330%								
8										
9	Thin_OL1			10.8		195,809	TON	$18.47	$3,616,592	$2,820,119
10	Miscellaneous		11.7%	10.8		1	Price	$423,141.29	$423,141	$329,954
11	Mobilization		4.6%	10.8		1	Price	$185,827.74	$185,828	$144,903
12	Construction added costs		10.1%	10.8		1	Price	$426,781.69	$426,782	$332,793
13										
14										
15	**22.8 Year Maintenance**	22.8								
16	Discount Rate:	2.758%								
17										
18	Mill_Med_OL1			22.8		195,809	SY	$21.31	$4,172,690	$2,243,982
19	OGFC		1.25	22.8		13,394	TON	$105.00	$1,406,357	$756,309
20	Miscellaneous		11.7%	22.8		1	Price	$652,748.52	$652,749	$351,034
21	Mobilization		4.6%	22.8		1	Price	$286,662.60	$286,663	$154,161
22	Construction added costs		10.1%	22.8		1	Price	$658,364.28	$658,364	$354,054
23										
24	**32.8 Year Maintenance**	32.8								
25	Discount Rate:	2.830%								
26										
27	Mill_Thin_OL1			32.8		195,809	SY	$13.66	$2,674,751	$1,070,909
28	OGFC		1.25	32.8		13,394	TON	$105.00	$1,406,357	$563,073
29	Miscellaneous		11.7%	32.8		1	Price	$477,489.67	$477,490	$191,176
30	Mobilization		4.6%	32.8		1	Price	$209,695.51	$209,696	$83,957
31	Construction added costs		10.1%	32.8		1	Price	$481,597.64	$481,598	$192,821
32										
33	**Salvage Value**	33								
34	Discount Rate:	2.830%								
35										
36				33				Treatment 3	$5,162,392.92	-$2,055,401
37										
38										
39	**Years in analysis:**		**Total Cost:**						**$22,241,450**	**$7,533,845**
40	33		End of service life	**44.8**	yrs					
41	Discount Rate:	2.830%								
42			**Equivalent Uniform Annual Cost:**							**$354,253**
43										

	A	B	C	D	E	F	G	H	I	J
1										
2	**ODOT AC Projection (#3)**									
3			% or					Unit		Present
4			Thick. (in.)	Year	Adjustment	Quantity	Unit	Price	Cost	Worth
5										
6	**10.8 Year Maintenance**	10.8								
7	Discount Rate:	2.330%								
8										
9	OGFC	100.0%	1.25	10.8		13,394	TON	$105.00	$1,406,357	$1,096,639
10	Miscellaneous		11.7%	10.8		1	Price	$164,543.81	$164,544	$128,307
11	Mobilization		4.6%	10.8		1	Price	$72,261.45	$72,261	$56,347
12	Construction added costs		10.1%	10.8		1	Price	$165,959.42	$165,959	$129,411
13										
14										
15	**24.8 Year Maintenance**	24.8								
16	Discount Rate:	2.783%								
17										
18	Mill_Med_OL1			24.8		195,809	SY	$21.31	$4,172,690	$2,112,361
19	OGFC		1.25	24.8		13,394	TON	$105.00	$1,406,357	$711,947
20	Fabric Reinforcement	x2		24.8		391,618	SY	$0.70	$274,133	$138,775
21	Miscellaneous		11.7%	24.8		1	Price	$684,822.03	$684,822	$346,681
22	Mobilization		4.6%	24.8		1	Price	$300,748.08	$300,748	$152,249
23	Construction added costs		10.1%	24.8		1	Price	$690,713.73	$690,714	$349,663
24										
25	**Salvage Value**	33								
26	Discount Rate:	2.830%								
27										
28				33				Treatment 2	$3,670,613.50	-$1,461,450
29										
30										
31	**Years in analysis:**		**Total Cost:**						**$13,009,199**	**$3,760,930**
32	**33**		End of service life	**40.8**	yrs					
33	Discount Rate:	2.830%								
34			**Equivalent Uniform Annual Cost:**							**$176,845**
35										

ODOT AC Projection (#4)

		% or Thick. (in.)	Year	Adjustment	Quantity	Unit	Unit Price	Cost	Present Worth
10.8 Year Maintenance	10.8								
Discount Rate:	2.330%								
OGFC	100.0%	1.25	10.8		13,394	TON	$105.00	$1,406,357	$1,096,639
Miscellaneous		11.7%	10.8		1	Price	$164,543.81	$164,544	$128,307
Mobilization		4.6%	10.8		1	Price	$72,261.45	$72,261	$56,347
Construction added costs		10.1%	10.8		1	Price	$165,959.42	$165,959	$129,411
24.8 Year Maintenance	24.8								
Discount Rate:	2.783%								
Mill_Med_OL1			24.8		195,809	SY	$21.31	$4,172,690	$2,112,361
OGFC		1.25	24.8		13,394	TON	$105.00	$1,406,357	$711,947
Fabric Reinforcement	x2		24.8		391,618	SY	$0.70	$274,133	$138,775
Miscellaneous		11.7%	24.8		1	Price	$684,822.03	$684,822	$346,681
Mobilization		4.6%	24.8		1	Price	$300,748.08	$300,748	$152,249
Construction added costs		10.1%	24.8		1	Price	$690,713.73	$690,714	$349,663
Salvage Value	33								
Discount Rate:	2.830%								
			33				Treatment 2	$3,211,869.08	-$1,278,802
Years in analysis:		**Total Cost:**						**$12,550,455**	**$3,943,578**
33		End of service life	**39.1**	yrs					
Discount Rate:	2.830%								
		Equivalent Uniform Annual Cost:							**$185,433**

ODOT AC Projection (#5)

		% or Thick. (in.)	Year	Adjustment	Quantity	Unit	Unit Price	Cost	Present Worth
10.8 Year Maintenance	10.8								
Discount Rate:	2.330%								
Thin_OL1			10.8		195,809	TON	$18.47	$3,616,592	$2,820,119
Miscellaneous		11.7%	10.8		1	Price	$423,141.29	$423,141	$329,954
Mobilization		4.6%	10.8		1	Price	$185,827.74	$185,828	$144,903
Construction added costs		10.1%	10.8		1	Price	$426,781.69	$426,782	$332,793
17.8 Year Maintenance	17.8								
Discount Rate:	2.634%								
AC Leveling Course	20.0%	1.5	17.8		58,743	CY	$160.00	$9,398,832	$5,916,836
OGFC		1.25	17.8		13,394	TON	$105.00	$1,406,357	$885,343
Miscellaneous		11.7%	17.8		1	Price	$1,264,207.15	$1,264,207	$795,855
Mobilization		4.6%	17.8		1	Price	$555,192.24	$555,192	$349,510
Construction added costs		10.1%	17.8		1	Price	$1,275,083.46	$1,275,083	$802,702
29.5 Year Maintenance	29.5								
Discount Rate:	2.825%								
Mill_Med_OL1			29.5		195,809	SY	$21.31	$4,172,690	$1,834,442
OGFC		1.25	29.5		13,394	TON	$105.00	$1,406,357	$618,278
Fabric Reinforcement	x2		29.5		391,618	SY	$0.70	$274,133	$120,517
Miscellaneous		11.7%	29.5		1	Price	$684,822.03	$684,822	$301,069
Mobilization		4.6%	29.5		1	Price	$300,748.08	$300,748	$132,218
Construction added costs		10.1%	29.5		1	Price	$690,713.73	$690,714	$303,659
Salvage Value	33								
Discount Rate:	2.830%								
			33				Treatment 3	$5,605,878.00	-$2,231,974
Years in analysis:		**Total Cost:**						**$31,687,357**	**$13,456,222**
33		End of service life	**43.2**	yrs					
Discount Rate:	2.830%								
		Equivalent Uniform Annual Cost:							**$632,733**

ODOT AC Projection (#6)

		% or Thick. (in.)	Year	Adjustment	Quantity	Unit	Unit Price	Cost	Present Worth
10.8 Year Maintenance	10.8								
Discount Rate:	2.330%								
OGFC		1.25	10.8		13,394	TON	$105.00	$1,406,357	$1,096,639
Miscellaneous		11.7%	10.8		1	Price	$164,543.81	$164,544	$128,307
Mobilization		4.6%	10.8		1	Price	$72,261.45	$72,261	$56,347
Construction added costs		10.1%	10.8		1	Price	$165,959.42	$165,959	$129,411
18.1 Year Maintenance	18.1								
Discount Rate:	2.674%								
Thin_OL1			18.1		195,809	CY	$18.47	$3,616,592	$2,243,184
Miscellaneous		11.7%	18.1		1	Price	$423,141.29	$423,141	$262,452
Mobilization		4.6%	18.1		1	Price	$185,827.74	$185,828	$115,259
Construction added costs		10.1%	18.1		1	Price	$426,781.69	$426,782	$264,710
28.3 Year Maintenance	28.3								
Discount Rate:	2.813%								
Mill_Thin_OL1			28.3		195,809	SY	$13.66	$2,674,751	$1,219,899
Miscellaneous		11.7%	28.3		1	Price	$312,945.86	$312,946	$142,728
Mobilization		4.6%	28.3		1	Price	$137,434.05	$137,434	$62,681
Construction added costs		10.1%	28.3		1	Price	$315,638.22	$315,638	$143,956
Salvage Value	33								
Discount Rate:	2.830%								
			33				Treatment 3	$1,603,085.59	-$638,267
Years in analysis:		**Total Cost:**						**$11,505,320**	**$5,227,307**
33		End of service life	**37.1**	yrs					
Discount Rate:	2.830%								
		Equivalent Uniform Annual Cost:							**$245,796**

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APPENDIX F

REALISTIC LCCA OF DJCP SECTIONS

	A	B	C	D	E	F	G	H	I	J
1										
2	**ODOT DJCP Projection (#1)**									
3			% or					Unit		Present
4			Thick. (in.)	Year	Adjustment	Quantity	Unit	Price	Cost	Worth
5	**23.2 Year Maintenance**	23.2								
6	Discount Rate:	2.762%								
7	**Treatment**	**Scope**								
8	Joint Rehabilitation Traveled Way			23.2		195,809	SY	$7.10	$1,390,244	$738,883
9	Miscellaneous		23.0%	23.2		1	Price	$319,756.10	$319,756	$169,943
10	Mobilization		4.9%	23.2		1	Price	$83,790.00	$83,790	$44,532
11	Construction added costs		9.6%	23.2		1	Price	$172,203.84	$172,204	$91,522
12										
13	**40.2 Year Maintenance**	40.2								
14	Discount Rate:	1.992%								
15	**Treatment**	**Scope**								
16	Grind			7.2		195,809	SY	$7.10	$1,390,244	$1,206,188
17	Miscellaneous		23.0%	7.2		1	Price	$319,756.10	$319,756	$277,423
18	Mobilization		4.9%	7.2		1	Price	$83,790.00	$83,790	$72,697
19	Construction added costs		9.6%	7.2		1	Price	$172,203.84	$172,204	$149,406
20										
21										
22	**41.2 Year Maintenance**	41.2								
23	Discount Rate:	2.102%								
24	**Treatment**	**Scope**								
25	Grind			8.2		195,809	SY	$7.10	$1,390,244	$1,172,223
26	Miscellaneous		23.0%	8.2		1	Price	$319,756.10	$319,756	$269,611
27	Mobilization		4.9%	8.2		1	Price	$83,790.00	$83,790	$70,650
28	Construction added costs		9.6%	8.2		1	Price	$172,203.84	$172,204	$145,198
29										
30	**Salvage Value**	33								
31	Discount Rate:	2.830%								
32										
33										
34				33				Treatment 1	$832,656.21	-$331,521
35										
36										
37										
38	**Years in analysis:**					**Total Cost:**			**$832,656**	**$713,360**
39	33		End of service life	**46.2**	yrs					
40	Discount Rate:	2.830%								
41			**Equivalent Uniform Annual Cost:**							**$33,543**
42										

L2

	A	B	C	D	E	F	G	H	I	J
1										
2	**ODOT DJCP Projection (#2)**									
3			% or					Unit		Present
4			Thick. (in.)	Year	Adjustment	Quantity	Unit	Price	Cost	Worth
5	**23.2 Year Maintenance**	23.2								
6	Discount Rate:	2.762%								
7	**Treatment**	**Scope**								
8	Joint Rehabilitation Traveled Way			23.2		195,809	SY	$7.10	$1,390,244	$738,883
9	Miscellaneous		23.0%	23.2		1	Price	$319,756.10	$319,756	$169,943
10	Mobilization		4.9%	23.2		1	Price	$83,790.00	$83,790	$44,532
11	Construction added costs		9.6%	23.2		1	Price	$172,203.84	$172,204	$91,522
12										
13	**34.2 Year Maintenance**	34.2								
14	Discount Rate:	1.750%								
15	**Treatment**	**Scope**								
16	Grind			1.2		195,809	SY	$7.10	$1,390,244	$1,361,600
17	Miscellaneous		23.0%	1.2		1	Price	$319,756.10	$319,756	$313,168
18	Mobilization		4.9%	1.2		1	Price	$83,790.00	$83,790	$82,064
19	Construction added costs		9.6%	1.2		1	Price	$172,203.84	$172,204	$168,656
20										
21										
22	**Salvage Value**	33								
23	Discount Rate:	2.830%								
24										
25										
26				33				Treatment 1	$214,472.05	-$85,392
27										
28										
29										
30	**Years in analysis:**					**Total Cost:**			**$214,472**	**$959,490**
31	33		End of service life	**43.2**	yrs					
32	Discount Rate:	2.830%								
33			**Equivalent Uniform Annual Cost:**							**$45,117**
34										

ODOT DJCP Projection (#3)

		% or Thick. (in.)	Year	Adjustment	Quantity	Unit	Unit Price	Cost	Present Worth
23.2 Year Maintenance	23.2								
Discount Rate:	2.762%								
Treatment	**Scope**								
Joint Rehabilitation Traveled Way			23.2		195,809	SY	$7.10	$1,390,244	$738,883
Miscellaneous		23.0%	23.2		1	Price	$319,756.10	$319,756	$169,943
Mobilization		4.9%	23.2		1	Price	$83,790.00	$83,790	$44,532
Construction added costs		9.6%	23.2		1	Price	$172,203.84	$172,204	$91,522
40.2 Year Maintenance	40.2								
Discount Rate:	1.992%								
Treatment	**Scope**								
Joint Rehabilitation Traveled Way			7.2		195,809	SY	$7.10	$1,390,244	$1,206,188
Miscellaneous		23.0%	7.2		1	Price	$319,756.10	$319,756	$277,423
Mobilization		4.9%	7.2		1	Price	$83,790.00	$83,790	$72,697
Construction added costs		9.6%	7.2		1	Price	$172,203.84	$172,204	$149,406
Salvage Value	33								
Discount Rate:	2.830%								
			33				Treatment 1	$832,656.21	-$331,521
Years in analysis:					**Total Cost:**			**$832,656**	**$713,360**
33		End of service life	**49.2**	yrs					
Discount Rate:	2.830%								
		Equivalent Uniform Annual Cost:							**$33,543**

	A	B	C	D	E	F	G	H	I	J
1										
2	**ODOT DJCP Projection (#4)**									
3			% or					Unit		Present
4			Thick. (in.)	Year	Adjustment	Quantity	Unit	Price	Cost	Worth
5	**23.2 Year Maintenance**	23.2								
6	Discount Rate:	2.762%								
7	**Treatment**	**Scope**								
8	Joint Rehabilitation Traveled Way			23.2		195,809	SY	$7.10	$1,390,244	$738,883
9	Miscellaneous		23.0%	23.2		1	Price	$319,756.10	$319,756	$169,943
10	Mobilization		4.9%	23.2		1	Price	$83,790.00	$83,790	$44,532
11	Construction added costs		9.6%	23.2		1	Price	$172,203.84	$172,204	$91,522
12										
13										
14	**Salvage Value**	33								
15	Discount Rate:	2.830%								
16										
17										
18				33				Treatment 1	$681,544.53	-$271,356
19										
20										
21										
22	**Years in analysis:**					**Total Cost:**			**$681,545**	**$773,525**
23	**33**		End of service life	**38.2**	yrs					
24	Discount Rate:	2.830%								
25			**Equivalent Uniform Annual Cost:**							**$36,372**
26										

L2

ODOT DJCP Projection (#5)

	A	B	C	D	E	F	G	H	I	J
3			% or					Unit		Present
4			Thick. (in.)	Year	Adjustment	Quantity	Unit	Price	Cost	Worth
5	**29 Year Maintenance**	29								
6	Discount Rate:	2.820%								
7	**Treatment**	**Scope**								
8	Thin_OL1			29		195,809	SY	$18.47	$3,616,592	$1,614,541
9	Miscellaneous		23.0%	29		1	Price	$831,816.21	$831,816	$371,344
10	Mobilization		4.9%	29		1	Price	$217,972.01	$217,972	$97,308
11	Construction added costs		9.6%	29		1	Price	$447,972.52	$447,973	$199,987
12										
13	**31 Year Maintenance**	31								
14	Discount Rate:	2.830%								
15	**Treatment**	**Scope**								
16	Thin_OL1			31		195,809	SY	$18.47	$3,616,592	$1,522,596
17	Miscellaneous		23.0%	31		1	Price	$831,816.21	$831,816	$350,197
18	Mobilization		4.9%	31		1	Price	$217,972.01	$217,972	$91,767
19	Construction added costs		9.6%	31		1	Price	$447,972.52	$447,973	$188,598
20										
21	**44 Year Maintenance**	44								
22	Discount Rate:	1.750%								
23	**Treatment**	**Scope**								
24	PC_Patch	30.00%		11		195,809	SY	$125.00	$7,342,838	$5,401,890
25	Miscellaneous		23.0%	11		1	Price	$1,688,852.63	$1,688,853	$1,242,435
26	Mobilization		4.9%	11		1	Price	$442,552.82	$442,553	$325,572
27	Construction added costs		9.6%	11		1	Price	$909,527.32	$909,527	$669,110
28	**Salvage Value**	33								
29	Discount Rate:	2.830%								
30										
31										
32				33				Treatment 2	$4,327,529.44	-$1,723,001
33										
34										
35										
36	**Years in analysis:**					**Total Cost:**			**$4,327,529**	**$2,713,338**
37	**33**		End of service life	**47**	yrs					
38	Discount Rate:	2.830%								
39			**Equivalent Uniform Annual Cost:**							**$127,585**
40										

	A	B	C	D	E	F	G	H	I	J
2	**ODOT DJCP Projection (#6)**									
3			% or					Unit		Present
4			Thick. (in.)	Year	Adjustment	Quantity	Unit	Price	Cost	Worth
5	**23.2 Year Maintenance**	23.2								
6	Discount Rate:	2.762%								
7	**Treatment**	**Scope**								
8	Joint Rehabilitation Traveled Way			23.2		195,809	SY	$7.10	$1,390,244	$738,883
9	Miscellaneous		23.0%	23.2		1	Price	$319,756.10	$319,756	$169,943
10	Mobilization		4.9%	23.2		1	Price	$83,790.00	$83,790	$44,532
11	Construction added costs		9.6%	23.2		1	Price	$172,203.84	$172,204	$91,522
14	**Salvage Value**	33								
15	Discount Rate:	2.830%								
18				33				Treatment 1	$214,472.05	-$85,392
22	**Years in analysis:**					**Total Cost:**			**$214,472**	**$959,490**
23	**33**		End of service life	**34.2**	yrs					
24	Discount Rate:	2.830%								
25			**Equivalent Uniform Annual Cost:**							**$45,117**

	A	B	C	D	E	F	G	H	I	J
1										
2	**ODOT DJCP Projection (#7)**									
3			% or					Unit		Present
4			Thick. (in.)	Year	Adjustment	Quantity	Unit	Price	Cost	Worth
5	**23.2 Year Maintenance**	23.2								
6	Discount Rate:	2.762%								
7	**Treatment**	**Scope**								
8	Med_OL1			23.2		195,809	SY	$21.31	$4,172,690	$2,217,691
9	OGFC		1.3	23.2		13,394	TON	$125.00	$1,674,235	$889,818
10	Miscellaneous		23.0%	23.2		1	Price	$1,344,792.69	$1,344,793	$714,727
11	Mobilization		4.9%	23.2		1	Price	$352,394.15	$352,394	$187,290
12	Construction added costs		9.6%	23.2		1	Price	$724,234.71	$724,235	$384,914
13										
14										
15	**Salvage Value**	33								
16	Discount Rate:	2.830%								
17										
18										
19				33				Treatment 1	$3,445,144.28	-$1,371,680
20										
21										
22										
23	**Years in analysis:**					**Total Cost:**			**$3,445,144**	**$3,022,760**
24	**33**		End of service life	**40**	yrs					
25	Discount Rate:	2.830%								
26			**Equivalent Uniform Annual Cost:**							**$142,135**
27										
28										

	A	B	C	D	E	F	G	H	I	J
1	**ODOT DJCP Projection (#8)**									
2			% or					Unit		Present
3			Thick. (in.)	Year	Adjustment	Quantity	Unit	Price	Cost	Worth
4	**14 Year Maintenance**	14								
5	Discount Rate:	2.486%								
6	**Treatment**	**Scope**								
7	Joint Rehabilitation Traveled Way			14		195,809	SY	$7.10	$1,390,244	$985,797
8	Miscellaneous		23.0%	14		1	Price	$319,756.10	$319,756	$226,733
9	Mobilization		4.9%	14		1	Price	$83,790.00	$83,790	$59,414
10	Construction added costs		9.6%	14		1	Price	$172,203.84	$172,204	$122,107
11										
12	**28 Year Maintenance**	28								
13	Discount Rate:	2.810%								
14	**Treatment**	**Scope**								
15	Joint Rehabilitation Traveled Way			28		195,809	SY	$7.10	$1,390,244	$639,884
16	Miscellaneous		23.0%	28		1	Price	$319,756.10	$319,756	$147,173
17	Mobilization		4.9%	28		1	Price	$83,790.00	$83,790	$38,566
18	Construction added costs		9.6%	28		1	Price	$172,203.84	$172,204	$79,260
19										
20										
21	**Salvage Value**	33								
22	Discount Rate:	2.830%								
23										
24										
25				33				Treatment 1	$982,996.92	-$391,379
26										
27										
28	**Years in analysis:**					**Total Cost:**			**$982,997**	**$1,907,554**
29	33		End of service life	**38**	yrs					
30	Discount Rate:	2.830%								
31			**Equivalent Uniform Annual Cost:**							**$89,696**
32										

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APPENDIX G

RECOMMENDATIONS OF IDAHO TRANSPORTATION DEPARTMENT

1) Keep the project manageable and straightforward by avoiding simultaneous implementation of new innovative techniques on the same project. For instance, this project had multiple variables in the form of new (or at least infrequently used) approaches, design methods, and materials. These included APTB contracting and the use of a perpetual pavement design method.
2) ITD should develop guidelines for determining when using APTB would be applicable. Factors that should be considered include using the process only when there is no preference for type of pavement to be used, size of project (i.e., a particular dollar value) Final Report for Innovative Contracting Practices 6 SEP-14 "Alternate Pavement Type Bidding" for which APTB should be used, and range of difference between life cycle costs for each type of pavement considered.
3) Decide on and incorporate APTB early in the project development phase. Some of the APTB problems identified during bidding of this project were related to preparing the alternate pavement design late in the project development process.
4) Ensure that the LCC adjustment factor for the asphalt pavement is a fair and representative amount. Also, all aspects of the future maintenance should be considered, e.g., traffic control costs should be included in the pavement maintenance performance for future mill and inlay/overlay of the asphalt pavement alternative versus sealing joints for the concrete alternative. ITD may want to meet with industry representatives and the Association of General Contractors (AGC) to decide on an acceptable method for making such determination of the adjustment factor.
5) Be mindful during the development of the project of the level of effort needed for traffic control staging when adjustments to the storm water inlets and manholes are necessary, especially when placing pavements that have intermediate layers. These adjustments may have potential costs associated with them.
6) Consider using the incentive/disincentive program for the QC/QA acceptance for plant mix pavement versus the thickness and profile incentives for the concrete pavement.
7) Be mindful of the available aggregates for concrete pavements. There are good aggregate sources in southwestern Idaho, but special consideration may be necessary for projects located in eastern, central, and northern Idaho.
8) Identify specific variables, such as climate and geographic area, related to performance of each pavement alternate. It may be that such variables are significant enough that ITD would want to specify a particular type of pavement and not go through the APTB process.
9) The length of the projects that are bid as alternate pavement types should be identical. Due to construction scheduling of adjacent projects, about a half mile of concrete was required for the concrete alternate that was not required for the asphalt alternate.
10) ITD should perform a long-term evaluation of the pavement performance and maintenance costs of this project to help determine the success of the APTB process. Appendix A: FHWA Approval