MISSOURI DEPARTMENT OF TRANSPORTATION

PAVEMENT DESIGN AND TYPE SELECTION PROCESS

PHASE I REPORT

March 2, 2004

**Review Conducted by
MoDOT/Industry**

Preface

This report has been developed to show the history of the MoDOT pavement design and type selection process and where the process is going in the future. The transparency of this process was intended to enlighten transportation users in Missouri and ensure MoDOT accountability in adhering to the process.

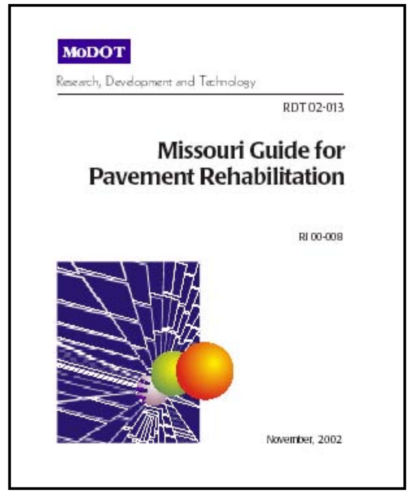
The report contains recommendations by the Pavement Team for various pavement design and type selection issues. These recommendations were not always reached by consensus of the Team, which included asphalt and concrete paving industry representatives, as well as MoDOT and FHWA representatives, because consensus could not be reached on all issues. In those cases MoDOT management made policy decisions based on the best data available at the time.

In closing, the Pavement Design and Type Selection Process is a very contentious issue all over the country. Almost every DOT is dealing with this issue in some form. There are no easy answers. However, MoDOT is committed to keeping abreast of technology changes and using industry resources to continually improve the Pavement Design and Selection Process, so that, ultimately, the people who use our transportation system are the benefactors.

If anyone wants to learn more about MoDOT's Pavement Design and Type Selection Process, they can contact MoDOT at http://www.modot.org, or call 1-888-ASK-MODOT.

Executive Summary

Faced with deteriorating pavements on one of the nation's largest state highway systems, inadequate fiscal resources and public demand for improved roadways, the Missouri Department of Transportation embarked on a project more than a year ago to ultimately improve the condition of its primary routes while providing the best pavement value to the citizens of Missouri.



The initial impetus for forming a Pavement Design and Type Selection Team was a report published by MoDOT's Research, Development and Technology unit in 2002 – "Missouri Guide for Pavement Rehabilitation" – that analyzed the historical performance of various pavement types in Missouri. At the same time, data showed that only 35 percent of the National Highway System (NHS) in Missouri (and other primary arterials) was in good or better condition. And, with dwindling financial resources, MoDOT was looking for ways to maximize the use of its limited amounts of funds.

So, in the fall of 2002, a Pavement Team was created. Its membership included representatives from MoDOT and the Federal Highway Administration, the Missouri Asphalt Paving Association and the American Concrete Paving Association, and asphalt and concrete paving contractors.

The team was charged to provide the public and stakeholders with two desired outcomes:

- the best pavement product that can be delivered within available resources.
- a clear understanding of the pavement design and selection process.

Pavement Team Members

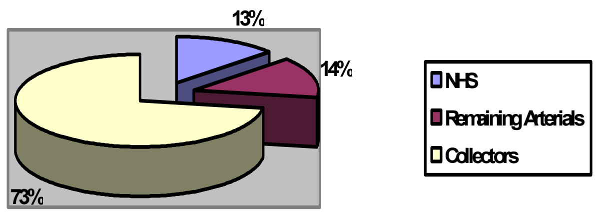
MoDOT	**Industry**
Dave Nichols, Project Development	Matt Ross, ACPA
Mike Anderson, District 5	David Yates, MAPA
Jay Bledsoe, Transportation Planning	Roger Brown, Pace Construction
John Donahue, RDT	Paul Corr, Fred Weber Inc.
Pat McDaniel, Construction & Materials	Kim Wilson, Clarkson Construction
Travis Koestner, Design	Donnie Mantle, APAC
Virgil Stiffler, FHWA	

Mara Campbell, MoDOT - facilitator

Involving industry in the process was a key component of the effort, not necessarily with a hope of building consensus but rather in having industry at the table so that its representatives had a clear understanding of the process and how it was developed.

Developing pavement strategies for MoDOT's entire 32,000-mile system was not the goal. Prior to formation of the team a MoDOT policy decision was made to maintain 23,000 miles of collector roads with a conventional thin-lift resurfacing program. That meant the team could focus its attention on the 9,000 miles of the state system (27 percent) that carries 86 percent of the traffic.

MoDOT System by Classification



Background

Examining MoDOT's pavement type selection process is nothing new. It's been done internally a number of times – most recently in 1998. Those past efforts, however, were conducted with only minimal, if any, input and contribution from the paving industry.

One of the problems faced in the past was a pervasive opinion among MoDOT District designers – those who actually put the projects together – that the time required to get a pavement type selection took too long and ultimately resulted in selection of the same pavement design as what existed on the previous project.

Industry had a number of issues, too, foremost of which was what was seen as a secretive, exclusive process. Past MoDOT policy did not call for sharing its life cycle cost analysis or data on specific projects with industry. That led to a perception that MoDOT was biased towards one industry or the other.

In the past, MoDOT has used an empirical pavement design method that is based on observations of performance in pavements with known dimensions and materials under specific climatic, geologic and traffic conditions. Industry felt that the use of this method led to overly conservative designs that led to Missouri having some of the thickest pavements in the country.

Why Now?

Both the Missouri Highways and Transportation Commission and MoDOT have heard the message loud and clear from the general public in all areas of the state – more dollars need to be invested in taking better care of Missouri's existing system of highways and bridges. That recognition has resulted in changes to MoDOT's strategic plan and to the revenue allocation strategies of the MHTC. Now there are only two major thrusts for the organization:

- Take better care of what we have.

- Finish what we've started.

Making headway in those two areas will build public trust, a critical step if Missourians are ever to fund its transportation system at a higher level.

An initial step has been to set a modest improvement goal: that the percentage of Missouri's NHS and principal arterials that are in good or better condition climb from 35 percent to 50 percent in the next 10 years. To do so while recognizing that MoDOT does not have the resources to build the ultimate solution everywhere requires a careful balancing act.

On one hand, and heeding the wishes of the public, MoDOT would like to build long-term solutions that enable its crews and contractors to "Get In, Get Out and Stay Out." On the other hand, though, less expensive solutions could allow MoDOT to make more immediate improvements to more miles of road – thereby reaching its goals more quickly, but the impact would be that we are out working on our roads more often.

Outcomes

One of the fundamental findings of the Pavement Team was that MoDOT add mechanistic qualities to its empirical design philosophy. Mechanistic-empirical (M-E) design methods use a mechanistic process to determine what stresses, strains and deflections a pavement will experience from external influences (i.e. load weight and location, temperature, etc.) and an empirical relationship to connect pavement response with pavement deterioration. Implementation of M-E pavement design will allow MoDOT to design the pavement with the right thickness for the specific conditions in each geographic area.

The team identified a number of other innovative pavement solutions, such as better subgrade and base treatments to extend pavement life.

Also, MoDOT will use better quality products to improve the life and durability of its pavements. Things like:

- Polymer Modified Asphalt (PMA) in our more heavily traveled Hot Mix Asphalt (HMA) overlays.

- Use of Stone Matrix Asphalt (SMA) mixes in our HMA overlays on Missouri's interstates.

- Use of Traditional HMA overlays, where appropriate.

- HMA overlays on rubblized Portland cement concrete.

- Jointed Plain Concrete Pavement (JPCP).

- Unbonded JPCP overlays.

A critical team recommendation to provide the most competitive prices for road improvements is the use of alternate bidding for pavements. To that end, 20 projects have been identified to provide more data for analysis as to the potential savings that can be realized.

Alternate bidding provides the opportunity for both asphalt and concrete contractors to bid on the two lowest cost designs head-to-head. It also brings more contractors to the bidding arena, which translates into more competition and ultimately lower cost to the taxpayer.

As of December 2003, MoDOT had two months of lettings behind it in alternate bidding of test projects. Two projects were awarded to asphalt contractors and two projects were awarded to concrete contractors. All four of these projects had more bidders than would normally have been the case had MoDOT bid only one type of pavement. The bottom line is the bids received were very competitive when compared to MoDOT engineers' cost estimates for these projects, which is in keeping with the team's belief that alternate bidding can and will bring great value to projects.

It should be noted, however, that there will be a limited number of projects where alternate bidding is not the right solution. For example, unique working conditions or very high traffic volumes could warrant that a specific pavement design and solution be defined.

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The team's work also underscored the importance of life cycle cost analysis (LCCA) – an economic assessment of competing pavement treatments considering all significant costs over the life of each alternative, expressed in equivalent dollars. The FHWA requires the LCAA process be used on the selection of long-term pavement solutions. MoDOT's

Design estimators are brought into the process to analyze pavement costs through their knowledge of the latest and most current prices. They will also make changes to the LCCA process as prices change and performance data changes for each pavement type.

Next Steps

To move past its Phase One recommendations, the team must transition to the new M-E pavement design model. This will require lab and field work to calibrate the M-E design program to Missouri conditions.

A number of other technical issues, delineated below, also remain to be resolved. Ultimately, though, MoDOT will realize more variability in its pavement thickness, which will mean that more dollars are available to fund more projects.

<u>Outstanding Phase II issues:</u>

- Finalize pavement performance standards criteria.
- Set evaluation criteria for composite pavements.
- Finalize what costs will be considered in LCCA, such as user costs, vehicle operation costs, etc.
- Determine salvage values for each design or rehabilitation strategy generated.
- Review the results from initial alternate bid pavement projects.
- Determine if alternate bids on pavements should be extended to rehabilitation projects where only thin HMA overlays have historically been used.
- Determine if staged construction is a valid design consideration.
- Determine if the design catalog to be generated should be on a project-by-project basis or on a regional or statewide basis.
- Develop methods to track the PTS process and to keep industry involved in the process.
- Determine if noise impact and friction need to become pavement design considerations.
- Determine the cost effectiveness of full-depth shoulders.
- Determine if recycled pavement savings are tangible and should be included in LCCA.
- Evaluate aggregate base designs, including drainage.
- Determine how preventive maintenance fits in LCCA.
- Identify how to capture maintenance expenditures on pavements for use in LCCA.

Conclusion

MoDOT is committed to bring the best value possible to its pavement solutions.

MoDOT is committed to keeping the paving industry involved in its paving process as we work in partnership to bring transportation solutions to our customers.

MoDOT recognizes that pavement design and the type selection process is dynamic and will change as more data is gathered and more lessons are learned.

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Glossary of Acronyms and Abbreviations

ACOL	Asphalt Concrete Overlay
ACPA	American Concrete Paving Association
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ADTT	Average Daily Truck Traffic
CPR	Concrete Pavement Restoration
DARWin	An AASHTO Software Program for Design and Analysis of Pavement Structures Using Microsoft Windows, based on the AASHTO Guide for Design of Pavement Structures - 1993
DOT	Department of Transportation
dTIMs	Deighton Transportation Information Management System
ESALs	Equivalent Single Axle Loads
FEM	Finite Element Model
FHWA	Federal Highway Administration
FY	Fiscal Year
HMA	Hot Mix Asphalt
ILLI-PAVE	University of ILLInois finite element flexible PAVEment analysis model
IRI	International Roughness Index
JPCP	Jointed Plain Concrete Pavement
JRCP	Jointed Reinforced Concrete Pavement
LCCA	Life Cycle Cost Analysis
MAPA	Missouri Asphalt Paving Association
M-E	Mechanistic-Empirical
MoDOT	Missouri Department of Transportation
NAPA	National Asphalt Paving Association
NHS	National Highway System
PCC	Portland Cement Concrete
PMA	Polymer Modified Asphalt
PSR	Present Serviceability Rating
PTS	Pavement Type Selection
QC/QA	Quality Control/Quality Assurance
RDT	Research, Development and Technology business unit of MoDOT
SHRP	Strategic Highway Research Program
SMA	Stone Matrix Asphalt
VE	Value Engineering

Glossary of Definitions

Design Life	The number of years a single pavement construction or rehabilitation treatment will last prior to the need for additional rehabilitation based on minimum performance standards.
Design Period	A combination of pavement treatment design lives. Equivalent design periods are compared in a life cycle cost analysis (LCCA) to determine the most cost-effective combination of treatments.
Discount Rate	The difference between the annual percentage rate of inflation and interest that money will accrue over an analysis period. Also known as "Opportunity Cost of Capital" in economic studies. For example, a department of transportation that decides to spend money improving a highway loses the investment opportunity to use this money elsewhere.
ESAL	Truck axle weight converted to a number of 18,000-pound, single-axle loads in terms of pavement damage equivalency. ESALs are summed together for a design period in pavement treatment performance analysis.
Life Cycle Cost Analysis	An economic assessment of competing pavement treatments, considering all significant costs over the life of each alternative, expressed in equivalent dollars.
Present Worth	Cost of future pavement treatments converted to a current time equivalency using a discount rate. Common cost denominator used in life cycle cost analysis.
Rehabilitation	Construction work necessary to return an existing roadway, including shoulders, to a condition of structural or functional adequacy. This could include partial removal and replacement of the pavement structure, but does not include normal periodic maintenance activities.
• ***Incremental***	Rehabilitation performed at periodic intervals to extend the service life of a pavement. These incremental rehabilitations are considered in the life cycle analysis for each pavement type. This does not involve adding thickness to the pavement structure, but work necessary to return the pavement to a condition of functional adequacy.
• ***Major***	Rehabilitation required at the end of the design life of a pavement, in the form of additional pavement structure (overlay ≥ 3-3/4 "), rubblization, or removal and reconstruction.
Routine Maintenance	Maintenance activities addressing the immediate or seasonal needs necessary to keep a roadway in working order. Generally, maintenance is performed by MoDOT forces and may include pothole patching,

crack sealing, snow removal, mowing, spot sealing, minimal pavement or bridge repairs, striping, signs and the replacement of traffic control devices.

Preventive Maintenance Proactive maintenance activities on good roadways to keep them in that condition as long as possible. May be contracted out or performed by MoDOT forces. Activities typically include some type of pavement seal.

Salvage Value The structural value of a pavement at the end of its design life or design period.

Staged Construction The building of roadways by staggering, on a predetermined time schedule, the construction of successive layers of structural pavement.

User Costs The money value during construction of highway user impacts, such as delay in travel time, used in a life cycle cost analysis.

Chapter One Pavement Team

Departments of transportation nationwide have recognized the need for pavement design and type selection process improvements. For this reason, and to address recent industry concerns, MoDOT organized a Pavement Team in November 2002 to conduct a review of its current pavement design and type selection processes. To make the review a truly collaborative process, MoDOT elected to utilize the good partnerships it has with the asphalt and concrete industries by including them on the Pavement Team. The inclusion of industry and their respective trade associations on this Team was an effort in the partnering spirit to demonstrate a sincere desire on MoDOT's part to eliminate any mystery regarding pavement design and type selection.

Table 1. Team Members

Name	**Organization**
Dave Nichols (Team Leader)	MoDOT
Mara Campbell (Facilitator)	MoDOT
Mike Anderson	MoDOT
Jay Bledsoe	MoDOT
Roger Brown	Pace Construction Company
Paul Corr	Fred Weber Inc.
John Donahue	MoDOT
Travis Koestner	MoDOT
Donnie Mantle	APAC Missouri Inc.
Pat McDaniel	MoDOT
Matt Ross	MO/KS Chapter of ACPA
Virgil Stiffler	FHWA
Kim Wilson	Clarkson Construction
David Yates	Missouri Asphalt Paving Association

At the first meeting, MoDOT Chief Engineer Kevin Keith gave the Team its direction and charter (Appendix A). After initial discussions the Team's desired outcomes evolved to:

- **Provide the public the best product that can be delivered within our current financial projections.**
  Goals for this outcome were:
  1. Design roadway structures at the lowest cost for the longest life that can be achieved.
  2. Use life cycle costs to determine the pavement type for Missouri primary routes -- approximately 9,000 miles of the state system.
  3. Improve the condition of MoDOT roads with funds available.
- **Provide a clear understanding of the pavement design and selection process for all stakeholders.**
  Goals for this outcome were:
  1. Provide a consistent and efficient pavement selection process.
  2. Provide a clear understanding of the pavement type selection process among all stakeholders.

3. Provide a written pavement type selection (PTS) process document with a clear set of criteria and expectations, including guidelines for stakeholders' involvement in the improvement of the process after implementation.

The Team's focus was specifically directed to the construction and rehabilitation of roadways of national or statewide significance. Collector (farm-to-market) routes and the few arterial routes with volumes less than 1,700 vehicles per day were excluded from the process. These routes will be managed through the application of periodic thin HMA overlays, which are intended to provide an adequate riding surface and minimize maintenance efforts.

Eliminating 23,700 miles of low-volume routes left approximately 9,000 miles of National Highway System (NHS) routes and other remaining arterials, which carry 85 percent of the traffic. Current funding levels and MoDOT's desire to improve the condition of these high-order routes will require the application of less-than-optimal pavement solutions in the near term on some facilities. Also, MoDOT will implement a thin-lift asphalt overlay program on the lower volume arterials currently in fair condition to improve more miles of pavement quickly while MoDOT pursues additional funding.

The team identified specific concerns and issues that needed to be addressed (see Appendix B for a complete listing of the initial concerns and issues). In the order of priority, they pertained to:

1. Pavement Design
2. Life Cycle Costs
3. Selection Process
4. Alternate Bidding
5. Value Engineering
6. MoDOT/Industry Relationship
7. Policy
8. Political Issues

In Phase I the Team selected the following areas of priorities in pavement design and type selection to discuss:

1. Pavement Type Selection Process (Chapter Two)
2. Performance Standards (Chapter Three)
3. Design Lives/Periods (Chapter Four)
4. Design Types (Chapter Five)
5. Design Model (Chapter Six)
6. Life Cycle Cost Analysis (Chapter Seven)
7. Alternate Pavement Design Bidding (Chapter Eight)
8. Interim Pavement Type Selection (Chapter Nine)

Chapter Two Pavement Type Selection Process

2.0 Introduction

The pavement type selection (PTS) process is used to determine the appropriate and most cost-effective pavement type for a specific project. The roadway design for each pavement type can be distinctly different (thickness, quantity, effect on other work, etc.) for each given project. Important considerations include the amount and type of traffic the roadway carries, the minimum performance serviceability allowed, the tolerable level of future maintenance, and the combined present worth costs of initial construction and future work. Pavement types are often predetermined, based on historical experience. Pavement design models verify that each pavement type being considered will meet minimum performance standards and not exceed certain distress criteria during their design lives. Alternate pavement types, that produce acceptable design model results, are compared and the most cost-effective solution is chosen.

2.1 Existing Pavement Type Selection Process

MoDOT has used a PTS process for years. Four common pavement types made up the PTS core group for new construction and major rehabilitation. A range of design thicknesses, based primarily on truck traffic and subgrade support, were derived from the 1986 AASHTO design model and compiled in tables in MoDOT's Project Development Manual (PDM). A spreadsheet life cycle cost analysis (LCCA) is run on the different pavement types, with very heavy emphasis on specific production costs.

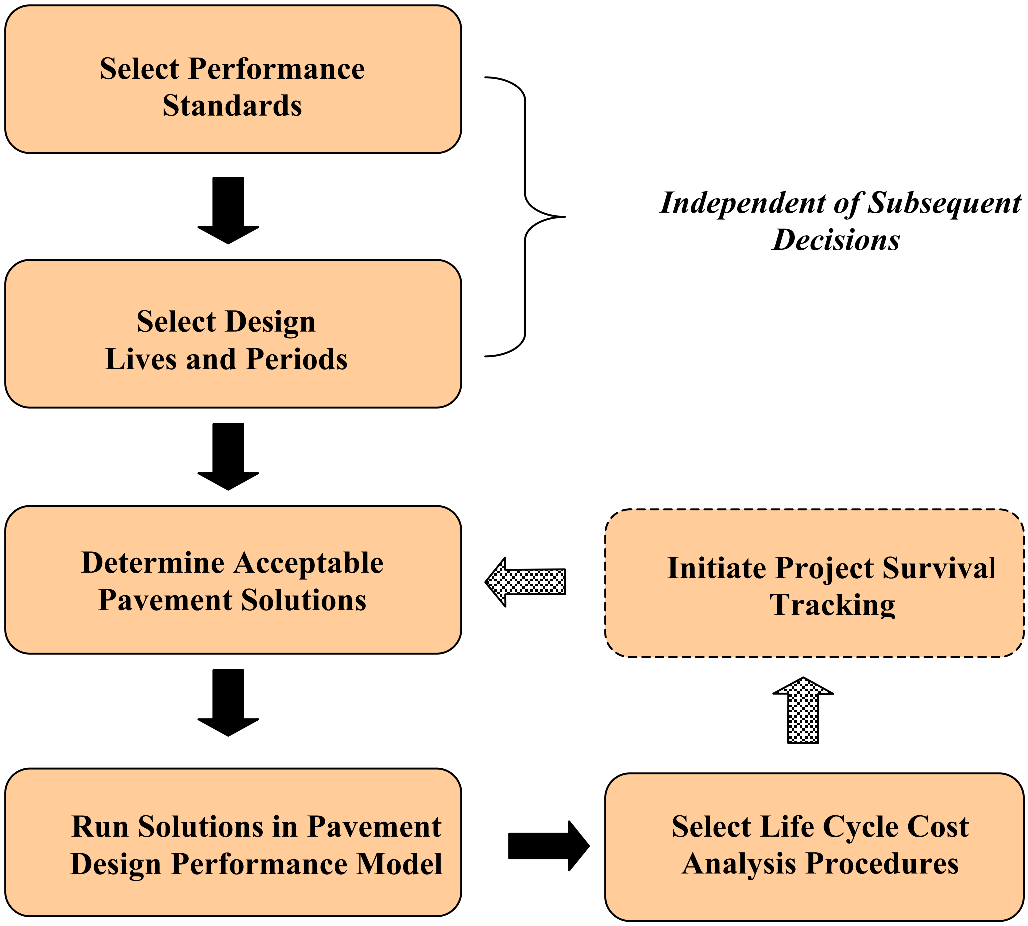
MoDOT's PTS has been used primarily to direct decision-making early in the design process, usually three-five years in advance of the award of a project. Therefore, it provides a purely rough estimate, based on average anticipated future supplier costs derived from current cost data, which may or may not reflect the material and construction costs for a specific pavement type at the time the project goes out for bid.

The Team directed their efforts towards identifying a PTS process that would accentuate meeting key performance criteria with state-of-the-art design modeling and determine life cycle costs closer to the time of the letting of a project in order to reflect current costs as much as possible.

2.2 Recommended Pavement Type Selection Process

The team identified key PTS components (Figure 1) for performing and refining over time the PTS process. These components were inherent, at least to some extent, in the existing PTS process, but were not magnified to the importance that they are in the following chapter recommendations.

Figure 1. Pavement Type Selection Process



Chapter Three Performance Standards

3.0 Introduction

Performance standards are the public's and owner agency's criteria for roadway acceptability. Minimum standards must be set before anything else is done in the PTS process. Standard types usually consist of distresses such as rutting, cracking, spalling, faulting, raveling, scaling, patching, etc. that are both visually distracting and unappealing and detrimental to the long-term structural health of the pavement. The most important standard is ride quality, to which most distresses contribute. No other performance standard is universal to all pavement types and no other standard is as readily judged by the driving public. Pavement type and cost become irrelevant if the roadway cannot successfully meet these standards. The common ride quality standard has become the International Roughness Index (IRI), which the FHWA requires for annual state roadway inventory reports.

3.1 Existing Performance Standards

MoDOT has used a composite performance standard, the present serviceability rating (PSR), for years. The PSR is a scoring index split evenly between roughness and visual distress[1]. Roughness is measured objectively with an Automated Road Analyzer (ARAN) (Figure 2), while visual distresses are manually interpreted and recorded from ARAN videos of the pavement surface. MoDOT collects ARAN data from all arterial routes once every year.

Figure 2. ARAN van for pavement performance data collection

MoDOT made an effort a few years ago to correlate public opinion of pavement quality with PSR ratings by conducting public "Road Rally" surveys around the state in which selected Missourians rated MoDOT roadways. Public opinion determined that a PSR score ≥ 32 was acceptable for the NHS, while ≥ 31 was acceptable for remaining arterials, but they were quite certain any roadway < 29, regardless of functional classification, was unacceptable. A marginal performance range existed between these limits. The threshold of 29 was nearly identical to the breakpoint between fair and poor pavements statistically derived several years previous to the "Road Rally" by the MoDOT pavement management section.

3.2 Recommended Performance Standards

The Team reviewed different performance standards for the evaluation of new pavement designs[2,3,4,5,6]. The Team gave the highest regard to the IRI standard, because of its applicability to all pavement types and its near universal acceptance by transportation agencies. The Team modified IRI performance criteria ranges recommended by the FHWA for Missouri's use in the PTS process (Table 2). These performance ranges were corroborated by the "Road Rally" results that correlated the subjective participant ratings to IRI measurements.

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

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

The Team selected visual distresses (Table 3) that contribute the most strongly to pavement performance. Not all the distresses shown could be measured by existing MoDOT equipment, however the Team believed that any successful pavement design model must be able to reliably predict these individual distress criteria. The Pavement Team chose not to set distress criteria minimums until further guidance becomes available.

Table 3. Distress Criteria for Flexible and Rigid Pavements

Flexible Pavements	Rigid Pavements
HMA surface Down Cracking (Longitudinal)	Transverse Cracking
HMA Bottom Up Cracking (Alligator/Fatigue Cracking)	Mean Joint Faulting
HMA Thermal Fracture (Transverse Cracking)	
Permanent Deformation (Rutting)	

3.3 Fiscal Impact

The impact is minimal.

Chapter Four Design Lives / Periods

4.0 Introduction

The design life of a pavement treatment is typically measured as the amount of time from initial construction to the performance standard-defined condition where rehabilitation is required. Minor and preventive maintenance treatments are usually considered part of the design life and do not trigger the end of design life.

The design period of a pavement treatment is actually a combination of treatment design lives, typically consisting of the original construction and the following multiple rehabilitation treatments. The primary purpose of having a design period is to provide a common time denominator with other treatment combinations in life cycle cost analysis (LCCA) comparisons.

4.1 Existing Design Lives/Periods

Design life expectations for Missouri pavement treatments have been based on historical survival trends. Ideally, desired design lives should be predetermined based on agency needs before selecting the treatment types that can reach these durations, however; the small number of practical pavement treatments available in Missouri have somewhat dictated the length of design lives used. Design lives for the primary pavement treatments are shown in Table 4.

Table 4. Existing Treatment Design Lives

Pavement Treatment	Current Design Life Expectation (Years)
Full-depth HMA	15
Conventional HMA Overlay	15
JPCP	25
Unbonded JPCP Overlay	25

The LCCA design period for the past decade has been 35 years. The treatment combinations used in LCCA are shown in Table 5.

4.2 Review of Missouri Historical Data

In order to develop realistic expectations for design lives and compare them with current MoDOT assumptions the Team closely reviewed historical survival and performance data that was available for pavement treatments in Table 5. Data was very limited for unbonded PCC overlays, diamond grinding and full-depth HMA, because of their past limited practice in Missouri.

Survival histories of full-depth HMA and PCC pavements in Missouri, obtained from MoDOT's pavement management database, are provided in Table 6.

Table 5. Existing 35-Year LCCA Design Period Treatments

Initial Treatment	1st Rehab Treatment	1st Rehab Time	2nd Rehab Treatment	2nd Rehab Time
New Full-depth HMA	Cold mill and replace travelway HMA wearing surface	Year 15	Cold mill and replace entire HMA wearing surface	Year 25
New JPCP	Diamond Grinding (and 2 % full depth repairs)	Year 25		
Conventional HMA Overlay	Cold mill and replace travelway HMA wearing surface	Year 15	Cold mill and replace entire HMA wearing surface	Year 25
Unbonded JPCP Overlay	Diamond Grinding (and 2 % full depth repairs)	Year 25		

Concrete pavements are broken out into two categories. Jointed reinforced concrete pavement (JRCP) was the most prevalent type until 1993. Virtually the entire Interstate system was constructed with JRCP. Since 1994 jointed plain concrete pavement (JPCP) design has been the only rigid design used. One important fact about the older PCC infrastructure noted by the Team was that the thickness designs were based on projected 20-year cumulative traffic loads that were usually achieved in a 10- to 15-year span.

Asphalt pavements are not broken out into specific types, but include small percentages of Superpave HMA and stone matrix asphalt (SMA) overlays besides the predominant conventionally designed HMA pavements.

Table 6. Weighted Average Pavement Life for Full-Depth HMA and PCC Pavements in Missouri

System[abc]	Original Pavement Type	Average Life to 1st Overlay	Miles in Sample	Average 1st Overlay Life	Miles in Sample	Average 2nd Overlay Life	Miles in sample
IS	JPCP	0	0	0	0	0	0
IS	JRCP	19.9	759	10.4	300	6.1	114
IS[d]	JRCP (Non-D)	21.0	494	11.4	193	6.3	64
US	JPCP	29.6	807	17.1	650	16.2	378
US	JRCP	27.5	645	16.9	303	15.0	52
MO	JPCP	35.6	359	17.9	270	20.9	64
MO	JRCP	29.7	114	18.0	82	16.6	35
IS	HMA	18.9	12	13.2	11	14.0	2
US	HMA	19.3	653	11.5	481	11.2	338
MO	HMA	20.7	3010	12.4	2521	10.1	1890

a. Ages are based on only pavements that have been overlaid at least one time.

b. No pavement built before 1958 is included in original life calculations on the interstate system to exclude interstate pavements built over existing PCC pavements routes.
c. Only I-44 is included in the calculation of full-depth HMA pavement life for Interstates.
d. Calculations exclude PCC pavements in all District 1 Counties and Clay, Platte and Jackson Counties in District 4 to exclude the effects of D-cracking.

Several conclusions can be drawn from this table. First, HMA overlays last an average of 10 – 11 years on the highest volume routes. Second, the presence of d-cracking-susceptible aggregate in the JRCPs had only a slight impact on decreasing average pavement life to the first HMA overlay and subsequent HMA overlay lives. Third, the lower the category of road system, the longer original treatments and rehabilitation treatments survived.

One limitation to survival history data is the lack of performance data. In other words, survival histories inform one of the age when rehabilitation *occurred*, but not when rehabilitation was *required* based on minimum acceptable performance limits. In the early 1990s interviews were conducted with MoDOT construction and maintenance personnel in District offices who were familiar with construction projects on specific routes. They revealed that rehabilitation usually occurred an average of three years after it was required based on their subjective views of pavement performance.

The Team also reviewed findings[7] derived from ARAN performance data. Average HMA overlay lives on high-volume PCC routes are shown in Figure 3. The 9-10 year range at which the trend lines in the graph cross the 29 PSR threshold closely approximates the average survival ages for HMA overlays in Table 6 if one corrects for the combination of Interstate and US routes in the divided NHS category and the three-year performance reduction determined from the field interviews. For example, the average of survival ages for first HMA overlays on interstate routes (10.4 years) and US routes (17 years) is 13.7 years. Subtracting three years from 13.7 leaves 10.7, which is within a year of the performance data average for first overlays (9.7 years).

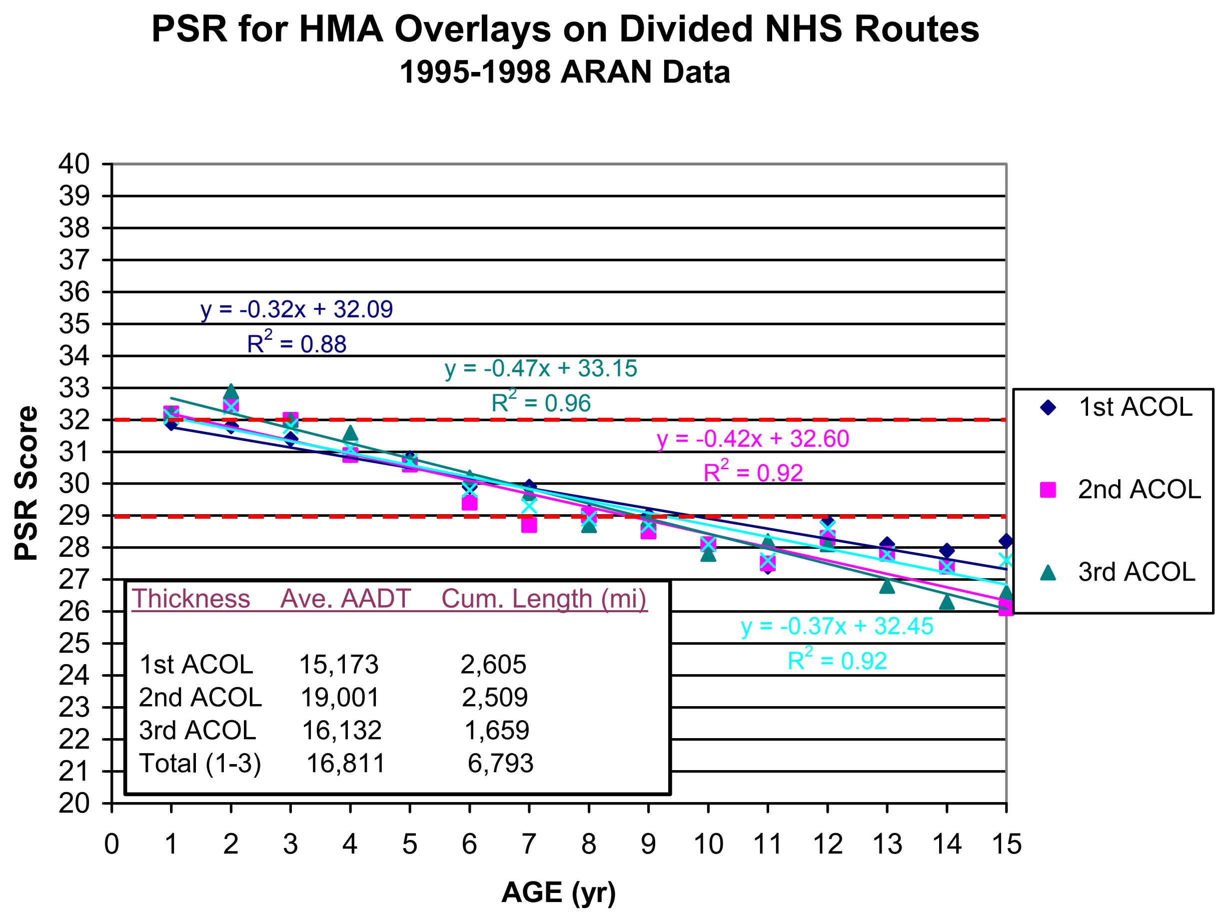


Figure 3. HMA Overlay Performance Data

Survival histories do not provide a complete history, however, because many pavements are unaccounted for because they have not yet been rehabilitated. Table 7 provides data about surviving pavement types in Missouri. It does not include surviving pavements less than 20 years old, which presents another difficulty with this analysis, and will not be considered in this discussion.

The significant mileage remaining that is older than 20 years meant the average lives from Table 6 somehow had to be adjusted. This was difficult to do since “closed” design lives cannot be simply averaged with “open-ended” design lives. Both must be recognized, but they must be considered separately. Therefore, based strictly on the data available from the two kinds of survival histories in Tables 6 and 7, the following is known about arterial routes:

- Interstate PCC pavements that were rehabilitated received their overlay at an average age of 20 years, while 39 percent of total Interstate PCC (excluding small mileage less than 20 years old) survived beyond 20 years, 36 percent survived beyond 25 years, and 21 percent survived beyond 30 years.
- Interstate HMA pavements totaled only 12 miles (less than one percent of the Interstate system), and survived an average of 19 years until their first overlay; no Interstate HMA pavements remain that have not been overlaid.

- US route PCC pavements that were rehabilitated received their overlay at an average age of 29 years, while 12 percent of total US route PCC survived beyond 30 years.
- US route HMA pavements that were rehabilitated received their overlay at an average age slightly over 19 years, while two percent of total US route HMA survived beyond 20 years and one percent survived beyond 30 years.

Table 7. Surviving Pavement Lives for Full-Depth HMA and Original PCC Pavements in Missouri

		Current Age in Years			
System	**Type**	21 - 25	26 - 30	31 - 35	>35
		Miles of Pavement			
IS	JRCP	46	182	193	72
IS	JPCP	0	0	0	0
US	JRCP	144	181	99	99
US	JPCP	27	40	19	30
MO	JRCP	27	1	4	14
MO	JPCP	31	24	27	45
IS	HMA	0	0	0	0
US	HMA	9	7	0	13
MO	HMA	92	23	34	74

4.3 Recommended Design Lives/Periods

To stay with the MoDOT philosophy of "get in, get out, stay out", the Team consensus was to consider only pavement designs or rehabilitation strategies that provide 15 years of service prior to requiring some sort of rehabilitation. The inability of the Team to reach a consensus agreement on design lives led to the following policy decisions, which are based on the best data available and will only be interim expectations until revised by the new AASHTO M-E design model:

Full-depth HMA – 20 years - The combination of limited Interstate survival data, much more substantial US route survival data, field personnel survey results, HMA mix improvements (SMA, polymer modified asphalt (PMA), etc.), and improved base/subbase design resulted in the 20-year expectation.

Conventional HMA Overlay (on PCCP) – 15 years - The combination of substantial Interstate and US route survival data, ARAN performance histories, and HMA mix improvements resulted in the 15-year expectation (see Chapter Five for an explanation of the design life asumption).

JPCP – 25 years - The combination of substantial Interstate and US route survival data, field personnel survey results, ARAN performance histories, and improved design features (thicker slabs, short joint spacing, tied shoulders, etc.) resulted in the 25-year expectation (see Chapter Five for an explanation of the full depth repair assumptions).

Unbonded PCC Overlay – 25 years - The combination of limited project performance data and improved design features resulted in the 25-year expectation.

These design lives are only expectations, minimum time frames that the Team believed were required for acceptable field performance within a longer design period. All treatment characteristics (thickness, material properties, etc.) must be determined using a pavement design methodology that will be discussed in Chapter 6.

The Team concluded that design periods could be extended beyond the current 35 years, because of higher design-life expectations with improved PCC and HMA pavements. Support for this idea came from learning of the design life assumptions that other regional states had. Table 8 summarizes the expectations of five transportation agencies.

Table 8. Other States' Extended Design Life Expectations

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

While some of the expectations of other states seemed more or less conservative compared to Missouri's, strong similarities existed. The Team believed a 45-year design period, with the treatments for new full-depth HMA and JPCP shown in Table 9, was realistic.

Table 9. Recommended Design Period Expectations for Existing Treatments

Initial Construction	Design Life	Future Rehabilitation Required During Design Life	
		When	What
Full-depth HMA Pavement	45 Years	20 Years	Mill 1 ¾" and replace in kind, traveled way only (24').
		33 Years	Mill 1 ¾" 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).

4.4 Fiscal Impact

New design-life expectations should have minimal impact since MoDOT is already building roads to the specifications assumed for the pavement types, with the exception of the use of PMA which will cause a slight increase in cost per wet ton of HMA and will be discussed in the next chapter.

Chapter Five Design Types

5.0 Introduction

The Team brainstormed possible pavement type treatments that had practical applications in Missouri. The work done in the preceding chapter predetermined much of this. However, the Team did have options to consider that were not part of the normal repertoire of MoDOT treatments.

5.1 Current Pavement Types

There are four primary types of pavement design used in Missouri:

- Full-depth HMA
- Conventional HMA overlay
- JPCP
- Unbonded JPCP overlay

Missouri has constructed a handful of full-depth HMA pavements using the Superpave mix design criteria (Figure 4). Arterial route thicknesses, which are derived from the 1986 version of the AASHTO Guide for Design of Pavement Structures, vary from 12 to 20 inches, depending on truck traffic and subgrade support. Although long-term performance is difficult to ascertain because they haven't been in place long enough, early performance of these pavements has been very good.

Figure 4. Full-depth HMA Superpave pavement on northbound US 63 in Boone County

Since 1994 all PCC pavements in Missouri have been built as JPCP (Figure 5). Driving lane slabs are paved 14 feet wide or two feet beyond the edge line. Joint spacing is 15 feet. Joints are doweled. Slab thickness on arterial routes is usually 12-14 inches, much greater than the older JRCP design. Performance to date has been very good.

Figure 5. JPCP on SB US 63 in Boone County

While the vast majority of high-volume arterial routes were originally paved with PCC, nearly all of these pavements, when rehabilitated, were overlaid with HMA. All arterial route HMA overlays have incorporated the Superpave mix design criteria for the past five years. Overlay thicknesses on arterial routes are currently 5 ¾" to 7 ¾" thick. Some wearing-course layers in Interstate overlays are stone matrix asphalt (SMA).

The major concern with these full-depth HMA overlays was the proliferation of reflective cracking from joint and working crack movement in the old pavement below. If not for frequent crack sealing maintenance operations, the area near the cracks would ravel and grow into potholes. Also, HMA overlays could not provide adequate structural support to prevent the underlying PCC pavements from continuing to deteriorate allowing excessive moisture to infiltrate the subgrade and keep it in a saturated and unstable condition. Since these pavements were constructed on non-drainable bases, edge drains would not alleviate the moisture problem. Most Team members did not believe the improved Superpave mix design would increase the average performance life to the 15-year minimum agreed upon because of preexisting conditions in the older pavement, or if it could the additional rehabilitation expected in a 45-year design period would be too frequent for public convenience. A telephone survey was conducted with nine other state transportation agencies regarding their HMA overlay performance lives on heavy-duty type routes and the responses uniformly gave a 10-year average, which agreed with the statistical findings for Missouri in Figure 3.

Eliminating conventional HMA overlays from the normal pavement type selection process meant leaving the two new construction designs (HMA and JPCP), but unbonded overlays as the only major rehabilitation design. Unbonded PCC overlays have been constructed on several sections of Interstate routes in Missouri. They have ranged from eight to 11 inches in thickness. The oldest was constructed in 1986 on the southbound lanes of Route I-55 in Pemiscot County. All of the unbonded PCC overlays are performing well and are exhibiting no distresses.

5.2 Other Pavement Types Considered

The Team at some point throughout the discussions considered the following pavement treatments:

Perpetual HMA pavement – The Team discussed the merits of "perpetual pavement," which is an expression coined by the National Asphalt Pavement Association (NAPA) and the Asphalt Institute (AI) to describe a full-depth HMA designed to control the two primary structural distresses that afflict it. A more thorough technical discussion of perpetual pavements is provided in Appendix C. Missouri has, at least partially, already adopted a perpetual pavement design for HMA pavements with the thicker pavements built during the past seven years.

Continuously reinforced concrete pavement (CRCP) – This PCC design was brought up as an alternate to the JPCP design. Only one example of this design exists in Missouri. The advantages are a inherently smoother ride and very minimal future maintenance expectations. The major disadvantage is an added cost of around $5 per square yard. The Team left this design open as an option for urban Interstate routes that would incur enormous user costs from maintenance activities, but was not selected as a primary type for normal pavement design.

HMA overlay on rubblized PCC – This rehabilitation option for old PCC pavements or even HMA overlaid PCC pavements has only been used once in Missouri at an experimental test site. The primary advantage is elimination of the reflective cracking through the HMA layer that plagues conventional HMA overlays. There is also some evidence that rubblized PCC can provide improved drainage.

Ultrathin whitetopping – This rehabilitation option is an alternative to thin HMA on existing HMA pavement. Three of these overlays have been constructed in Missouri within the past five years. The primary advantage is strong resistance to rutting, particularly in locations where this is a major concern because of slow moving heavy traffic such as at intersections or turning lanes. The disadvantage is the increase in cost incurred from saw-cutting the overlay into panels and from the fibers sometimes added to the mix. In light of the elimination of the collector system, which probably presented the greatest opportunity for whitetopping, from pavement type selection consideration, the Team viewed this as a specialized strategy that would be cost effective in certain situations, but would not be commonly considered in most LCCA scenarios.

5.3 Subgrade Stabilization

MoDOT has historically only specified soil stabilization as a contract work item when exceptionally weak subgrades are encountered or a project completion needs acceleration prior to an anticipated wet season of the year. Otherwise, for years Missouri contractors have had the option to stabilize subgrade soils on construction projects, but MoDOT only paid a flat $1 per square yard, which basically covered the cost of the stabilizer. MoDOT's philosophy had always been that soil stabilization is a benefit to the contractor as much as to MoDOT and that soil stabilization provides no long-lasting structural value to the pavement, perhaps five years at the most.

The Team was swayed by presentations from the asphalt industry consultant about the benefits of proactively specifying subgrade stabilization as a routine design procedure. Not only would the contractor complete construction more quickly under adverse conditions, the stronger foundation would enhance initial pavement smoothness, which would have a lasting influence during the design life of the pavement.

5.4 Base Courses

Two-foot rock base is specified beneath pavements when the rock is available within the project limits or when there is an economical local source. A position paper on how the rock-base thickness was derived at two feet was given to the Team and is provided in Appendix D of this report. The Team considered whether the rock base could be reduced to 18 inches or less in thickness without compromising support and drainage. They also wondered if the savings in material might be partially lost by the need for more rock crushing. A separate MoDOT technical team investigated this issue more closely and recommended maintaining the two-foot rock base for heavy- and medium-duty pavements and reducing the thickness for light-duty pavements.

The MoDOT technical team also provided the Pavement Team with recommendations for new aggregate base designs. A copy of those recommendations is provided in Appendix E. Pavement Team industry members were requested to review these recommendations for feasibility of construction and cost. Increasing the slope of the subgrade from two percent to four percent received favorable comments, but concerns over the base thicknesses were raised. It was also questioned if an aggregate base is needed beneath HMA pavements. These issues have not yet been addressed and are to be resolved as part of the second phase efforts of the Pavement Team.

5.5 Recommended Pavement Types

The Team believed three (JPCP, full-depth HMA, and unbonded JPCP overlay) of the existing four primary pavement types were working well on high-volume arterial routes and their use should continue. The fourth pavement type, conventional HMA overlay, did not have the survival or performance history in Missouri to indicate it could be relied on for the minimum design life required.

An HMA overlay on rubblized PCC (Figure 6) was selected by the Team as the new fourth alternative. The advantages of HMA overlays on rubblized PCC over conventional HMA overlays have been recognized by experts in the asphalt industry[8].

Figure 6. Rubblization with a multiple-head breaker

A policy decision was made to enhance the performance of full depth and overlay HMA pavements on most arterial routes through the use of polymer modified asphalts (PMA) in the top two lifts. Interstate routes would further require stone matrix asphalt (SMA) for the wearing course. The asphalt binder selection criteria is shown in Table 10. These changes to the HMA mix design enabled the Team to expect the 20-year design life shown back in Table 9. This design life expectation was also applied to HMA overlays on rubblized PCC.

Another issue that generated much discussion was full depth repairs in PCCP at 25 years. The existing design life assumption at 25 years had been two percent. A combination of past construction data and M-E model predictions (explained more fully in Appendix F) was used to lower the expectation to one and a half percent.

Table 11 modifies Table 9 to reflect the current recommended pavement treatments. The Team did not reach a consensus agreement on these design lives. They are based on the best data available and will only be interim expectations until revised by the new AASHTO M-E design model.

Table 10. Asphalt Binder Selection Criteria

TYPE OF CORRIDOR	LOCATION	Type of Construction	TYPE OF MIX	ASPHALT BINDER
Heavy Duty	Districts 1-6	Full Depth Asphalt	Surface mixture (SP125 or SMA) and first underlying lift	PG 76-28
	Districts 7-10	Full Depth Asphalt	Surface mixture (SP125 or SMA) and first underlying lift	PG 76-22
	All Districts	Full Depth Asphalt	Remaining Underlying Lifts	PG 64-22
	All Districts	Asphalt Overlays	Surface mixture (SP125 or SMA) and first underlying lift	PG 76-22
			Remaining Underlying Lifts	PG 64-22
Medium Duty	Districts 1-6	Full Depth Asphalt	Surface mixture (SP125) and first underlying lift	PG 70-28
	Districts 7-10	Full Depth Asphalt	Surface mixture (SP125) and first underlying lift	PG 70-22
	All Districts	Full Depth Asphalt	Remaining Underlying Lifts	PG 64-22
	All Districts	Asphalt Overlays	Surface mixture (SP125) and first underlying lift	PG 70-22
			Remaining Underlying Lifts	PG 64-22
Light Duty	Districts 1-6	Full Depth Asphalt	Surface mixture (SP125 only)*	PG 64-28
			Remaining Underlying Lifts	PG 64-22
			Surface Mixture (Secs 401 and 402 Mixtures) and Underlying Lifts	PG 64-22
	Districts 7-10	Full Depth Asphalt	All Mixtures	PG 64-22
	All Districts	Asphalt Overlays	All Mixtures	PG 64-22

Table 11. Recommended Pavement Types

Initial Construction	Design Period Treatments
Full-depth HMA pavement (all – top two lifts polymer modified, Interstate – top lift SMA)	20 years – 1st overlay (travelway) 33 years – 2nd overlay (entire surface)
JPCP	25 years – diamond grind and 1.5 % full depth repair
HMA overlay on rubblized PCC (all – top two lifts polymer modified, Interstate – top lift SMA)	20 years – 1st overlay (travelway) 33 years – 2nd overlay (entire surface)
Unbonded JPCP Overlay	25 years – diamond grind and 1.5 % full depth repair

Exceptions to these rehabilitation treatments will be granted by policy decision based on project/corridor location, traffic conditions and financial constraints. The I-70 corridor is an example, where portions of it will receive conventional HMA overlays, which should provide acceptable performance for up to 15 years prior to the beginning of expected total reconstruction. For non-Interstate arterials thinner HMA overlays with shorter design lives will still be a viable alternative. Other individual arterial locations may receive this treatment either for the reasons stated above or as a bondbreaker for future unbonded JPCP overlay construction.

Subgrade stabilization shall be included in projects where weak subgrade soils are encountered. MoDOT will predetermine the stabilization limits and area based on dynamic cone penetrometer (DCP) tests. Illinois DOT guidelines will be used to determine the depth of subgrade stabilization (Appendix G). The DCP will also be used to verify that acceptable levels of stabilization are acquired during construction. Provisions will also be provided in the specifications that will require at the end of each workday that the grading shall drain water away from the work area. Two pay items will be provided for the payment of stabilized subgrades, one for material and one for placement.

The Pavement Team discussed the pros and cons of reducing the rock-base thickness without reaching consensus. The proposal was submitted to MoDOT leadership for a policy decision. Based on a review of the information provided, a policy decision was made to reduce the rock-base thickness to 18 inches for all pavements. The decision was based on the belief that the rock base was more permeable than originally speculated and 18 inches would protect the pavement with an adequate retention reservoir during heavy rains.

5.6 Fiscal Impact

An increase in cost is expected from standardizing the use of PMAs in the upper two HMA layers on most arterial routes and an SMA wearing course on Interstate routes. The change from thinner conventional to thicker HMA overlays on rubblized PCCP will also increase total costs. Polymer-modified asphalt will initially increase HMA wet tonnage costs by 5-10 percent, depending on the binder grade, but will gradually lessen as supplier stockpiles increase and the old binders disappear. SMA will increase HMA wearing course tonnage costs up to 15 percent, depending on the location. The Team believed these changes were critical to obtaining acceptable performance in these high traffic areas over a 45-year design period.

Using thinner conventional HMA overlays in specific locations will allow MoDOT to avoid investing money on longer-term pavement strategies that will be replaced many years before their expected design life is expended. They will also allow the delay of more expensive capital investments until additional funding is available, within a reasonable time frame.

Specifying subgrade stabilization as contract work items in projects with weak soils will add 5-10 percent to paving costs.

Changing rock base thickness from 24 inches to 18 inches will reduce base costs by approximately 30 percent.

Chapter Six

Design Model

6.0 Introduction

Once the performance standards and design lives are determined for particular pavement treatments, the transportation agency must have a means of predicting the performance levels of the pavement treatments over the design lives/periods to ensure that minimum criteria are met at all times. This procedure is accomplished with a pavement design model.

6.1 Current Design Model

The design standards for HMA and PCC pavements in place at the time of this review were based on the 1986 AASHTO guidelines[9]. The 1986 AASHTO Guide is an empirical design and was adopted by MoDOT for determining pavement thicknesses in 1993. A position paper on the rationale and pavement assumptions used in deriving the pavement thicknesses tables in use since 1993 was provided to Team members for review and is included in this report as Appendix H.

6.2 Other Design Models

Because both paving industries have continually questioned the current pavement design thickness standards as being too conservative, the Team decided that there was a need to review different pavement design models, ranging from empirical to mechanistic-empirical designs. Empirical design methods are based on observations of performance of pavements with known dimensions and materials under specific climatic, geologic and traffic conditions. Mechanistic-empirical design methods use a mechanistic process to determine what stresses, strains and deflections a pavement will experience from external influences (i.e. load weight and location, temperature, etc.) and an empirical relationship to connect pavement response with pavement deterioration. A comprehensive narrative explaining empirical and mechanistic-empirical designs is provided in Appendix I.

After a review of available pavement design models, the Team focused its efforts on reviewing the new mechanistic-empirical AASHTO 2002 Pavement Design Guide for determining the design thickness for HMA and PCC pavements and ILLI-PAVE as an alternative design for determining the design thickness for HMA pavements. ILLI-PAVE is an iterative finite element flexible pavement analysis model, which is explained more fully in Appendix J.

Draft versions of the AASHTO 2002 Guide software were obtained, and pavement design iterations were run to evaluate the sensitivity of inputs and to evaluate design outputs. A consultant to MAPA provided presentations on M-E pavement designs, focusing on the ILLI-PAVE design program and the perpetual HMA pavement design concept.

From MoDOT's perspective, the shortcoming of adopting ILLI-PAVE as a MoDOT design standard would require adopting a separate design program for concrete pavements. Adopting different pavement designs based on different parameters, inputs or principles would not allow MoDOT to truly know if the designs generated for HMA and PCC pavements were equivalent.

6.3 Recommended Design Model

Because of questions regarding pavement type equality, a policy decision was made by MoDOT to adopt the AASHTO 2002 Guide upon its completion. MoDOT, with the assistance of a qualified consultant, will perform the lab and field data testing and subsequent distress model calibration required to predict long-term pavement performance for each construction and rehabilitation type as accurately as possible with the new M-E design program. Calibrating the distress models are essential in providing a high level of confidence that the results generated by mechanistic-empirical designs are reliable. A discussion about an initial attempt by the Team to generate coefficients for the HMA fatigue distress model is provided in Appendix J.

6.4 Fiscal Impact

Costs for the conversion from the present empirical AASHTO design method to the new M-E AASHTO design method are expected to be nearly $500,000. These costs include the consultant fee to guide MoDOT through the distress-model calibration process, develop materials-testing protocols and data-gathering procedures, and provide a user-design document; and MoDOT labor and material costs to perform the necessary lab tests for distress model calibration. These costs would primarily be paid for with Federal-aid SPR funds that cannot be used for construction projects. Undetermined future costs, which will be required for MoDOT staff to track pavement performance and recalibrate distress models, will be absorbed in MoDOT's normal operating budget.

Chapter Seven

Life Cycle Cost Analysis

7.0 Introduction

Life cycle cost analysis (LCCA) selects the most cost-effective solution out of two-or-more equivalent pavement design strategies with the same design periods. At this point, based on the best information available, the transportation agency has made the most prudent choice of pavement types.

7.1 Current LCCA Procedure

The cost analysis spreadsheet used by MoDOT to estimate the most cost-effective pavement type (HMA or PCC) for a specific project was developed in 1997 by a task force consisting of personnel from MoDOT, FHWA and both paving industries. A copy of the spreadsheet, along with explanations on assumptions used, was provided to the Team. A thorough review of the spreadsheet and sample cost analyses by industry members identified questionable assumptions and flaws within the spreadsheet. Even though a correction factor was utilized in the spreadsheet to rectify such flaws, the team believed this was not acceptable and concluded that to fix the spreadsheet would be a major undertaking and would be beyond the scope of this team. So as an alternative, the Team looked at existing cost analysis spreadsheets that could be adopted to replace the 1997 cost analysis spreadsheet.

7.2 Other LCCA Methods

One alternative was the Asphalt Pavement Alliance Life Cycle Cost Analysis Program, Version 3.1. This LCCA program calculates the net present value of different pavement alternatives using either deterministic or probabilistic analyses as described in a FHWA publication[10].

The Asphalt Pavement Alliance LCCA program was handicapped by the large number of variables and assumptions that had to be considered to run the analysis, thus making it almost impossible to justify the results generated for each pavement type selection. Based on the fact that there is already considerable disagreement on what should be considered in life cycle costs, it was believed that this LCCA program would just magnify the problem.

As another alternative, the Team reviewed the cost-based procedures used by MoDOT Design estimating personnel for paving costs. For this task three spreadsheets are used: 'Concrete paving using a ready-mix plant', 'Concrete paving using a mobile batch plant', and 'Superpave asphalt'. Details regarding the spreadsheets are in Appendix K. The State Design Engineer reviewed the history of final estimating at MoDOT for the Team. It was highlighted that all factors available at the time of estimate formulation are taken into consideration and that the final estimates are the best representation of market value that MoDOT has. MoDOT design estimators try to obtain the latest material quotes and the project staging, and assume reasonable production rates on a project-specific basis. Through discussions with contractors, material suppliers, and MoDOT construction personnel, the estimators have gained valuable knowledge and continue to improve their processes whenever possible. The final estimates are on average very close to the bids received on projects with a three-year average of –2.6 percent under the awarded bids on work that the Federal Highway Administration monitors, which is approximately $1.5 billion worth of work.

7.3 Recommended LCCA Procedures

Based upon this information and a thorough review of the estimator's spreadsheets, industry Team members were comfortable with the process and gave preliminary consensus for adopting MoDOT estimator spreadsheets for determining life cycle costs. However, consensus regarding theLCCA design life assumptions for different incremental rehabilitation treatments could not be reached among the Team members, which led to a policy decision to reinstate alternate pavement design bidding, that is discussed fully in the next chapter. Therefore, LCCAs will be performed primarily to determine adjustment factors for alternate bidding, rather than for PTS.

7.4 Fiscal Impact

No fiscal impact is expected to occur.

Chapter Eight Alternate Bidding for Pavements

8.0 Introduction

Alternate bidding for pavements pits two or more equivalent designs against one another in a competitive environment. In the case of pavements, where there are two primary industries, the procedure requires an HMA and a PCC strategy with equivalent performance expectations for the full design period.

8.1 Missouri Experience

Missouri experimented with this concept in 1996 by letting five federal-aid projects with alternate HMA and PCC pavement designs. Concurrence from the Missouri FHWA Division Office and cautionary agreement from both paving industries was received. The positive result from the alternate bidding experiment was that two projects yielded significant savings, approximately $770,000 total, from the engineer's estimate on the original design.

Alternate bidding for pavements occurred again in 1998, but was not pre-planned. Two projects were originally sent out for bids with only one paving design. Because of their complexity, only one contractor submitted a bid on each project, and those bids were deemed excessive and consequently were rejected. The projects were posted for bids a second time, but this time with alternate pavement designs. The bids actually came in higher, a reflection on the complexity of constructing those two projects under traffic and that alternate bids on pavements are not applicable to all situations.

The one major negative aspect of alternate bidding was disagreement by the paving industries over design-life assumptions. For those five experimental projects, an adjustment factor for the difference in present worth costs for future rehabilitation was added to each HMA bid (since the HMA designs had projected higher future costs than the PCC designs), solely for determining the low bidder. This issue could not be resolved to both industry's satisfaction and at the time dampened enthusiasm for letting any more project proposals with alternate bidding on pavements.

Another negative aspect of the alternate bid experience, from MoDOT's point of view, was the extra work required to design plans and to compute bid quantities for two pavement types. This issue was probably aggravated by the short time allotted for designers to add the alternate designs to the five projects. Designers were concerned they did not have enough time to adequately tabulate additional pavement and earthwork quantities and to address other alternate pavement design considerations.

8.2 Alternate Bidding Issues

After reviewing the report on the initial five alternate bid projects and discussing the pros and cons of alternate bidding, the Pavement Team believed that the negative aspects could be worked out to the satisfaction of all parties and concluded that allowing alternate bids on pavements is an excellent tool for achieving the lowest cost for the longest life. Industry Team members also believed that, even if they could not completely agree on LCCA design life assumptions, alternate bids still kept the door open for their pavement type being selected. Also, alternate bids make the selection process less time dependent, reflecting truer material and construction costs than the existing PTS process which is performed 3-5 years prior to the letting of a project.

The Team analyzed each component of the alternate pavement design bidding issue to make the process as equitable as possible.

8.2.1 Method of Payment

The Team discussed if payment for HMA mixes should be by wet tonnage, by mix component tonnage or by the square yard. Because payment by wet tonnage vs. by components was being discussed by another industry/MoDOT Team, the consensus of the Pavement Team was to let the other Team resolve this issue, and for the alternate bid projects, to pay for HMA mixes as currently specified by components, based on square yards of pavement constructed. Square yards was the preferred method because it maintained a more equivalent field between how the pavements will be paid for, whereas payment by the ton for HMA mixes could include payment for material wasted and would allow payment for placing additional thickness above the plan-design thickness.

8.2.2 Quality Control / Quality Assurance

Another issue discussed to keep the initial construction costs as equivalent as possible was requiring quality control / quality assurance (QC/QA) for the PCC pavement alternate. QC/QA specifications have been a MoDOT standard for HMA paving projects for several years, whereas only five experimental QC/QA PCC paving projects are currently under construction. The concrete industry Team members saw no problem with incorporating the new PCC QC/QA specifications for the alternate bid projects, with the following exceptions: (1) the specifications need to be changed to reflect what the concrete industry and MoDOT have agreed upon on what the air void content should be behind the paver; (2) the texturing requirements need to be addressed in the specification to address problems encountered on the five experimental projects; and (3) the pavement smoothness specifications need to be revised to reflect the same requirements as specified for HMA pavements.

8.2.3 Innovative Contracting

The Team discussed innovative contracting techniques that could be used, if necessary, on alternate pavement design projects. After reviewing a variety of methods the Team preferred the ‘A+B’ bidding process, which encouraged innovative thinking and new technology in a manner that would benefit these types of projects. In an ‘A+B’ bid the ‘A’ portion of the bid is for the items to perform the the work and the ‘B’ portion is the bidder’s number of closure units multiplied by MoDOT’s specified road user cost for having that project’s roadway closed for a certain amount of time. MoDOT would allow a maximum incentive of five to 10 percent for innovative contracting procedures to maintain a reasonable benefit/cost ratio for user-cost reduction.

8.2.4 Value Engineering

Allowing a contractor to change a pavement type after the award of a project by value engineering, which is not allowed under current MoDOT specifications, was considered an alternate way to address the concerns of the PTS being performed so far ahead of the project letting. An exception might be changing the shoulder type, which in certain situations could be evaluated as a value engineering idea. However, by going to alternate bids on pavements, the Team realized value engineering pavement types became a non-issue and will only be readdressed if alternate bidding on pavements is abandoned.

8.2.5 Planned Stage Construction

Planned stage construction allows an entity to initially construct a thinner HMA pavement, thereby lowering initial construction costs and using those savings to construct or rehabilitate other roadways within the entity's system. Team members from the asphalt industry proposed this as a means for MoDOT to provide the public the best value that could be delivered with current available resources, meeting the Pavement Team's first desired outcome. Their position is that, when the second stage of construction is required on these roadways, funds will be made available to meet those needs. The counter arguments given were that more uncertainty exists for future major capital spending and that reducing structure could violate the minimum design life required for arterial route construction and rehabilitation. Also, planned construction would incur additional costs for raising guardrail, shaping slopes, addressing drainage issues and other related incidental construction items. It was concluded that this issue could be explored further with the M-E design model.

8.2.6 LCCA Assumptions

The most contentious alternate bidding issues amongst Team members were the assumptions used to determine LCCA costs, particularly rehabilitation design intervals within the design period. The Team tackled these issues one at a time.

8.2.6.1 Rehabilitation Intervals

The number and times of pavement rehabilitation during a design period have a significant impact on life cycle costs. The inability to gain consensus on this issue from all stakeholders was the main reason why alternate bids on pavements were not used in five years. The current Pavement Team debated this issue and couldn't gain consensus, so a policy decision by MoDOT leadership had to be made in the interim to use the rehabilitation intervals shown in Table 10 in Chapter Five. This issue should will be discussed further when M-E solutions are developed.

8.2.6.2 Maintenance Costs

A 1995 investigation on the costs for routine maintenance performed by MoDOT forces found annual expenditures on HMA and PCC pavements to be very similar. Those results are shown in Table 12. Although the costs would have increased since 1995, they are believed to have kept the same relative proportion between types.

The maintenance records generally reflect only the cost involved and the type of pavement on which the work was performed. The records have limitations, however. They do not indicate what specific work was performed, such as sealing cracks or joints, fixing potholes, spalls, or raveled areas, performing pavement repair, etc. They also do not indicate whether an HMA pavement is a full-depth design or an overlay on a PCC pavement. Finally, they do not specify a direction on dual-lane facilities, so if one direction consists of a HMA overlay and the other a PCC pavement, it's not possible to know on which pavement the work was done. However, these limitations were considered inconsequential when maintenance costs are compared to the total LCCA costs on pavements (life cycle costs for heavy duty roadways are in the range of $500,000 - $700,000 per directional mile for rehabilitation projects and $1,400,000 - $1,600,000 for new pavement projects per directional mile).

The Team consensus was not to include maintenance costs in the LCCA at this time. However, the Team believed that maintenance costs are important and MoDOT should take steps to improve documentation of ongoing maintenance work on pavements to alleviate the above problems. When documentation improves, use of maintenance costs in LCCA should be reevaluated.

Table 12. Maintenance Expenditures on HMA and PCC Pavements

Year	System	Surface Type	Miles	Total Dollars Expended	Cost per Mile
1993	IS	PCC	850	$1,927,000	$2,267
	IS	HMA	1,460	$3,592,000	$2,460
1993	US	PCC	1590	$2,744,000	$1,726
	US	HMA	3550	$5,959,000	$1,679
1994	IS	PCC	840	$1,696,000	$2,019
	IS	HMA	1520	$3,125,000	$2,056
1994	US	PCC	1630	$2,772,000	$1,701
	US	HMA	3590	$6,277,000	$1,748

8.2.6.3 Salvage Values

The Team had no practical means to predict what the salvage value would be at the end of the design period for either HMA or PCC pavements. The newer pavement designs could only yield about 10 years worth of data at best, so salvage values would be extremely hypothetical. Current MoDOT LCCA assumptions are that salvage values are unknown, but equal, therefore unnecessary to include in the comparison, however; the Team believed salvage values should be included in future pavement LCCA. It is anticipated that upon implementation of the AASHTO M-E model, remaining lives for final rehabilitation treatments can be estimated and their respective salvage values can be prorated.

8.2.6.4 Discount Rate

The Team was informed that MoDOT currently used a four-percent discount rate, which is based on historical data in Missouri and concurs with what is recommended by the U.S. Office of Management and Budget (OMB). Some industry members questioned if this rate was still applicable, since surrounding states used lower discount rates. MoDOT's Resource Management Unit found that the four-percent discount rate was probably valid for the last decade, but because of current economic factors, lower discount rates are more appropriate and should be variable depending on the year being discounted. They recommended using the discount rates established by OMB for treasury notes for future value present worth calculations.

The Team decided to adopt the OMB discount rates for alternate bids and future LCCA, with the understanding that these discount rates would need to be reviewed on a regular basis and adjusted as needed. At the time of this report, the OMB discount rates were as follows:

3-Year	5-Year	7-Year	10-Year	30-Year +
1.6%	1.9%	2.2%	2.5%	3.2%

Note: Can interpolate between years given to determine discount rate.

8.2.6.5 User Costs

User costs are not currently calculated into the existing PTS process. However, a user-cost spreadsheet was developed for use based on FHWA recommendations, and user costs have been calculated for several projects for educational practice and to evaluate the impact of user costs in the LCCA. Previous preliminary calculations have shown that estimated user costs significantly affect PTS outcome for projects with high Average Daily Traffic (ADT) counts, i.e., as more people are inconvenienced during the life of a pavement, the more it costs society in lost time and wages. The argument for using user costs is that it would benefit society to spend more upfront to provide a pavement that is as maintenance free as possible for these high-trafficked routes. Therefore, user cost becomes a tool to justify higher quality (i.e. longer lasting, lower maintenance) pavements for high ADT routes.

The Team heard counter arguments for not considering user costs. First, it is difficult to estimate the time of delays (time to perform the work, initially and in the future, e.g., to interrupt traffic periodically to apply a low-cost rehabilitation versus applying a more expensive and permanent rehabilitation) and to place a cost on those delays (sometimes to the tune of thousands of dollars per hour of delay), making these factors difficult to substantiate and open to scrutiny. Second, user savings do not come back into the budget to supplement the extra expenditures associated with reducing user costs, hence it becomes an administrative decision as to how much extra one is willing to pay for that outside, intangible saving. For these reasons, user costs in the past have only been used in limited cases for PTS determination, usually when the life cycle costs are similar and the project is in a densely populated urban area.

The Team needs to further review the impact on adopting user costs into the LCCA process. With their current limited knowledge of the impact of using user costs in LCCA, Team consensus was not to use user costs in the alternate pavement bid projects. User costs will be analyzed in more detail as part of the Phase II process.

8.2.6.6 Incidental Construction, Engineering, and Mobilization Costs

Indirect project construction costs include incidental construction, engineering and mobilization costs. The Team consensus was to include all of these associated costs in the LCCA for alternate pavement design bidding (Table 13). Establishing these costs was recently aided by the Federal directive for all public agencies receiving Federal-aid funds to set up a consistent means of associating value with their infrastructure by July 1, 2001 in accordance with GASB-34 Federal Standards.

Preliminary engineering (design) and construction engineering (inspection and materials testing) cost percentages for all types of construction were based on 472 MoDOT projects awarded between April 1, 1995 and June 1, 2003 and were calculated by the Planning unit. Mobilization and miscellaneous cost percentages (any construction costs other than grading, drainage, paving and bridges) for new construction, based on actual bid prices for FY 2001 through FY 2003, were calculated by the Design unit. These processes and results were reviewed by internal auditors as well as outside auditors to confirm they met GASB-34 Standards. The Design unit also used cost data from the limited number of thin HMA overlay and diamond-grinding projects available to estimate mobilization and miscellaneous costs for these rehabilitation treatments.

Table 13. Indirect LCCA Construction Costs

Costs Description	Average Percentage of Construction Costs
Mobilization (new construction)	**5.0**
Miscellaneous (new construction)	**20.0**
Mobilization (thin HMA overlay)	**3.0**
Miscellaneous (thin HMA overlay)	**9.5**
Mobilization (diamond grinding)	**1.9**
Miscellaneous (diamond grinding)	**9.5**
Preliminary Engineering (all)	**3.6**
Construction Engineering (all)	**5.9**

8.3 Recommendations

The Team consensus was to implement alternate bids on one major paving construction or rehabilitation project in each district by the 2004 or 2005 construction year. Ten projects were initially selected by the Team to incorporate alternate bids on pavements, and ten more were added later by MoDOT. Table 14 provides a listing of these projects. In anticipation of the successful implementation of this endeavor, the Pavement Team hopes to expand the use of alternate bidding on pavements for all Interstate or major arterial route projects consisting of full depth pavement construction or major rehabilitation work, with the understanding there will be cases where allowing an alternate may not be feasible or desirable. For this reason, MoDOT will reserve the right to limit where alternate bids on pavements will be allowed. For locations where alternate bidding is not used MoDOT will document justification for the decision.

Identifying the projects early resolved the one negative aspect that was raised previously by designers of not having adequate time to prepare the plans for alternate bids. The task of preparing plans for alternate bids was also simplified somewhat by the Pavement Team'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. The Team reviewed guidelines and the job special provision used for the previous alternate bid projects and decided to incorporate them for the 2004-2005 alternate bid projects. A final draft of those procedures and the job special provision is provided in Appendix L.

Initially industry representatives on the Team agreed to use existing design-life assumptions for the interim until more accurate mechanistic-empirical answers for predicting future performance on each pavement type became available. However, because assumptions for the frequency and magnitude of future rehabilitation have a direct impact on the adjustment factor and any changes made to them can help tip the bids in favor of one or the other paving industry, the Team revisited this issue on several occasions. Interim procedures are discussed in the next chapter.

8.4 Fiscal Impact

Theoretically, alternate pavement design bidding should result in overall savings in project costs because of the increase in bidding competition between the HMA and PCC industries. The experimental projects let in 1996 verified this was possible. It is not yet possible to determine an average expected savings in either dollars or percentage of cost until more projects are let and cost trends are better established. Additional work for completion of alternate bid project plans will raise design costs slightly, but the increase should be controlled through longer lead time for plan preparation.

Table 14. Alternate Bid Projects

Rte.	County	Job No.	Letting Date	Location	Length (Miles)	Original PTS Design	Description of Work
118	Holt	J1S0612	01-04	0.9 to 2.3 mi. E/O Rte. P	1.4	PCC	Grading & Paving
63	Randolph	J2P0487	06-04	N/O Jacksonville to N. Bus. Rte. 63 at Moberly	10.0	PCC	Grading & Paving
63	Adair and Macon	J2P0485	12-03	S/o Kirksville to Rte. 36	21.5	AC	Grading & Paving
61	Clark	J3P0422	11-03	Iowa State Line to 0.7 mi. N/O Rte. 63 and Rte. 136 Spur	6.4	PCC	Paving
13	Ray `	J4P1102K	09-03	BNSF Railroad to the Mo. River	2.3	PCC	Paving
13	Ray	J4P1102L	06-05	Rte. 10 to BNSF Railroad	3.4	PCC	Paving
94	Callaway	J5S0351C	10-04	4.0 mi. E/O Rte. CC to 1.0 mi. E/O Rte. D	1.0	HMA	Grading & Paving
I-44	Franklin	J6I0735E	10-04	W/O Viaduct St. in Pacific to St. Louis Co. Line	2.3	N/A	Grading & Paving
MM	Jefferson	J6S1637	11-03	2.06 mi. E/O Rte.30 to 2.13 mi. W/O Rte. 21	0.9	HMA	Grading & Paving
71	McDonald	J7P0601H	10-03	2.1 mi. S/O Pineville to Arkansas State Line	6.1	PCC	Paving
13	St. Clair	J7P0604	06-04	1.3 mi. S/O Rte. 54 to Polk Co. Line	2.5	PCC	Grading & Paving
13	Polk	J8P0590B	06-04	St. Clair County Line to 1.1 mi. S/O Rte. 123	6.6	PCC	Grading & Paving
I-44 WB	Pulaski	J9I0507	11-03	0.2 mi. W/O Phelps County Line to 1.6 mi. E/O Rte. Y	5.9	PCC Overlay	Paving
I-55 SBL	New Madrid	J0I0854	10-04	Rte. EE to Pemiscot County Line	9.1	PCC Overlay	Paving

Rte.	County	Job No.	Letting Date	Location	Length (Miles)	Original PTS Design	Description of Work
I-44 WB	Crawford	J9I0514	?	Phelps CL to 0.6 mi W/O Rte. H	12.5	N/A	Paving
I-44 WB	Laclede	J8I0749	11/05	0.4 mi W/O Gasconade River Bridge to 0.5 mi W/O Rte. F	8.1	N/A	Paving
I-44 EB	Greene	J8I0754	11/05	0.1 mi W/O BL 44 to 0.1 mi W/O Rte 65	2.1	N/A	Paving
I-44	Greene	J8U548B	?	I-44 and Rte 65 interchange	0.8	N/A	Grading and Paving
I-44	Lawrence	J7I0721	?	0.5 mi E/O Jasper CL to 10.0 mi E/O Jasper CL	9.5	N/A	Paving
60	Stoddard	J0P0572D , E and F	?	Rte 60 and Relocated Rte 51 Interchange		N/A	Grading and Paving
I-44	Phelps Co.	J9I0484, and B	6/04	Rte D to Sugar Tree Road Int.	3.7	PCCP	Grading and Paving

Chapter Nine Interim Pavement Design

9.0 Introduction

The Team's major decisions to convert MoDOT's pavement design method from the existing AASHTO empirical method to the new AASHTO M-E method and to use alternate pavement design bidding on all new construction and major rehabilitation of arterial routes left one important unresolved issue: How would pavement types be designed in alternate bid projects prior to full implementation of the M-E method?

9.1 Interim Design Method

The need for an interim design method led to extensive discussions. The easiest solution was to continue using current PTS procedures for pavement thicknesses and rehabilitation intervals for the two new construction types and two major rehabilitation types (Table 10), however; there was one problem: designs for HMA overlays on rubblized PCC did not exist in the current procedures.

Therefore, the AASHTO design-based DARWin software program was used to compute a standard *HMA overlay thickness on rubblized PCC*. A range of subgrade resilient moduli and rubblized layer coefficients, upon which the overlay thickness outcomes were partly dependent, were explored as options. Ultimately, a 12-inch HMA overlay thickness was judged structurally reasonable, based on the generated outputs and the typical project location conditions. This procedure is explained in Appendix M.

The asphalt industry Team members believed that at 12 inches, a HMA overlay on rubblized PCC would not be competitive with an eight-inch unbonded PCC overlay. However, based on the pavement design computations, other Team members believed that lowering the HMA overlay thickness below 12 inches could not yet be justified until M-E solutions with the new AASHTO design validated the structural capability of thinner overlays.

The Team decided to maintain the current eight-inch *unbonded JPCP overlay* thickness. This thickness was originally derived from the 1986 AASHTO Pavement Design Guide. A recent FHWA report[11] on unbonded PCC overlays concluded that unbonded PCC overlays are long-term rehabilitation solutions expected to provide a level of service and performance life comparable to that of new PCC pavements. It also stated that the risk of poor performance is significantly lower for unbonded JPCP overlays ≥ 8 inches than thinner unbonded overlays. The thickness design will be revisited when the AASHTO M-E method is implemented.

9.2 Recommendations

For *full-depth HMA and JPCP construction*, consensus was reached by the Team to use MoDOT's current design thicknesses, based on the 1986 AASHTO Guide for Design of Pavement Structures.

For HMA overlays on rubblized PCC, a policy decision, based on results from the 1986 AASHTO Guide for Design of Pavement Structures, was made to use 12-inch overlay thicknesses.

For unbonded PCC overlays, the current eight-inch thickness will continue to be used.

9.1 Fiscal Impact

No fiscal impacts, other than the ones discussed in other chapters for pavement types and alternate design bidding, are expected to occur using these interim procedures,.

Chapter Ten

Phase II Objectives

Many of the issues to be resolved in the second phase of the Pavement Team's efforts are dependent on the calibration of the AASHTO M-E Pavement Design program to Missouri conditions and the subsequent generation of M-E designs for the pavement types selected by the Team.

Issues remaining to be resolved in the second phase during 2004 are as follows, but not necessarily in the order of priority:

- Finalize pavement performance standards criteria.
- Set evaluation criteria for composite pavements.
- Finalize what costs will be considered in LCCA, such as user costs, vehicle operation costs, etc.
- Determine salvage values for each design or rehabilitation strategy generated.
- Review the results from initial alternate bid pavement projects.
- Determine if alternate bids on pavements should be extended to rehabilitation projects where only thin HMA overlays have historically been used.
- Determine if staged construction is a valid design consideration.
- Determine if the design catalog to be generated should be on a project-by-project basis or on a regional or statewide basis.
- Develop methods to track the PTS process and to keep industry involved in the process.
- Determine if noise impact and friction need to become pavement design considerations.
- Determine the cost effectiveness of full-depth shoulders.
- Determine if recycled pavement savings are tangible and should be included in LCCA.

References

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