MoDOT Pavement Preservation Research Program
Volume VI, Pavement Treatment Trigger Tables/Decision Trees and Treatment Candidate Selection Process

Prepared by
David N. Richardson, PhD, PE, FACI
S. Michael Lusher
Missouri University of Science and Technology Department of Civil, Architectural and Environmental Engineering

Final Report Prepared for Missouri Department of Transportation
October 2015 Project TRyy1141 Report cmr16-004

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
cmr 16-004

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
MoDOT Pavement Preservation Research Program. Volume VI, Pavement Treatment Trigger Tables/Decision Trees and Treatment Candidate Selection Process

5. Report Date
August 6, 2015
Published: October 2015

6. Performing Organization Code

7. Author(s)
David N. Richardson, PhD, PE, FACI http://orcid.org/0000-0002-6964-882x; S. Michael Lusher

8. Performing Organization Report No.
NUTC R300

9. Performing Organization Name and Address
Missouri University of Science and Technology
1870 Miner Circle
Rolla, MO 65409

10. Work Unit No.

11. Contract or Grant No.
MoDOT project #TRyy1141 (Task 5)
NUTC project #00039112
USDOT contract #DTRT06-G-0014

12. Sponsoring Agency Name and Address
Missouri Department of Transportation (SPR) http://dx.doi.org/10.13039/100007251
Construction and Materials Division
P.O. Box 270
Jefferson City, MO 65102

Center for Transportation Infrastructure and Safety/NUTC program
Missouri University of Science and Technology
220 Engineering Research Lab
Rolla, MO 65409

13. Type of Report and Period Covered
Final report (June 2012-August 2015)

14. Sponsoring Agency Code

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. MoDOT research reports are available in the Innovation Library at http://www.modot.org/services/or/byDate.htm. This report is available at http://library.modot.mo.gov/RDT/reports/TRyy1141/cmr16-004v6.pdf.

16. Abstract
The objective of Task 5 was the development of pavement treatment trigger tables and the treatment candidate selection process. The input to the trigger tables entails such factors as an overall condition indicator, smoothness, individual distress types-extent-severity (e.g. thermal cracking, block cracking, fatigue cracking, longitudinal cold joint cracking, joint reflective cracking, longitudinal wheel path cracking, longitudinal edge breakup, patches and potholes, raveling, polishing, stable rutting, corrugations and shoving, bumps and sags, bleeding, D-cracking, pop-outs, spalling, corner cracks, faulting), pavement type, history of treatment, and some measure of traffic, through a surrogate such as Surface Age. Output is one or more potential appropriate treatments, which would consider pavement condition, traffic, climate (which affects construction timing and treatment performance), work zone duration (e.g. traffic control issues), time of year construction, construction quality risk, availability of quality contractors and quality materials, longevity of treatment, and availability of funding. Trigger tables include preservation treatments (chip seals, micro-surfacing, slurry seals, ultrathin bonded asphalt wearing surface (UBAWS), crack sealing, crack filling, thin overlays, mill and fill, profile milling, hot in-place recycling, cold in-place recycling, diamond grinding, whitetopping, load transfer retrofit and joint repair, and partial/ full depth repair).

17. Key Words
Evaluation and assessment; Level of service; Maintenance equipment; Pavement maintenance; Pavement management systems; Pavement performance; Preservation; Rehabilitation (Maintenance)

18. Distribution Statement
No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)
Unclassified.

20. Security Classif. (of this page)
Unclassified.

21. No. of Pages
122

22. Price

MoDOT PAVEMENT PRESERVATION RESEARCH PROGRAM
MoDOT TRyy1141

FINAL REPORT

VOLUME VI
PAVEMENT TREATMENT TRIGGER TABLES/DECISION TREES
and
TREATMENT CANDIDATE SELECTION PROCESS

August 6, 2015

Prepared for the
Missouri Department of Transportation

by

David N. Richardson, PhD, PE, FACI
Department of Civil, Architectural and Environmental Engineering
Missouri University of Science and Technology

S. Michael Lusher
Department of Civil, Architectural and Environmental Engineering
Missouri University of Science and Technology

EXECUTIVE SUMMARY

This research was performed by the Missouri University of Science and Technology. The general objective of Task 5 was to provide a manual that the Missouri Department of Transportation (MoDOT) can use to select the most appropriate pavement treatment for a given roadway project. The selection procedure includes cost assessment methods. Salient to any pavement management system is the process of determining potential treatment options, and the subsequent selection of the final treatment choice. Task 5 thus entails the development of pavement treatment trigger tables and the treatment candidate selection process.

Armed with the treatment tables and the selection process, MoDOT will be able to select appropriate treatments by use of treatment matrices showing the most appropriate applications for given specific site conditions and then be able to perform a cost analysis for each candidate treatment. The idea in using a decision table is to decide which optional treatments will be required to keep a route in the "Good" system rating, move the rating of a given road from "Poor" into "Good", or in an extreme case, move it from "Poor-Unsafe" to "Poor-Safe". The final selection of the optimum treatment from the possible ones would be done in a network prioritization activity (not part of this research project).

The input to the trigger tables entails such factors as an overall condition indicator, smoothness, individual distress types-extent-severity (e.g. thermal cracking, block cracking, fatigue cracking, longitudinal cold joint cracking, joint reflective cracking, longitudinal wheel path cracking, longitudinal edge breakup, patches and potholes, raveling, polishing, stable rutting, corrugations and shoving, bumps and sags, bleeding, D-cracking, pop-outs, spalling, corner cracks, faulting), pavement type, history of treatment, and some measure of traffic, through a surrogate such as Surface Age.

Output is one or more potential appropriate treatments, which would consider pavement condition, traffic, climate (which affects construction timing and treatment performance), work zone duration (e.g. traffic control issues), time of year construction, construction quality risk, availability of quality contractors and quality materials, longevity of treatment, and availability of funding. Trigger tables include preservation treatments (chip seals, micro-surfacing, slurry seals, ultrathin bonded asphalt wearing surface (UBAWS), crack sealing, crack filling, thin overlays, mill and fill, profile milling, hot in-place recycling, cold in-place recycling, diamond grinding, whitetopping, load transfer retrofit and joint repair, and partial/ full depth repair). The Guidance Document manual is included as an appendix to this report.

AUTHOR ACKNOWLEDGEMENTS

The research reported herein was sponsored by the Missouri Department of Transportation (MoDOT) and the National University Transportation Center (NUTC) at the Missouri University of Science and Technology (Missouri S&T). The research was performed by Missouri S&T. The authors wish to thank Clayton Reichle for his many hours in the laboratory.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Organization of the Report

The following report is part of a research project on pavement preservation performed by the Missouri University of Science and Technology (Missouri S&T) and the University of Missouri-Columbia (UMC) on behalf of the Missouri Department of Transportation (MoDOT). The overall report consists of a summary volume followed by six detailed technical volumes. This volume is one of the detailed volumes: *Task 5 - Pavement Treatment Trigger Tables/Decision Trees and Treatment Candidate Selection Process*.

1.2 Background

Fig. 1.1 shows a flow diagram of the pavement management process envisaged in this project.

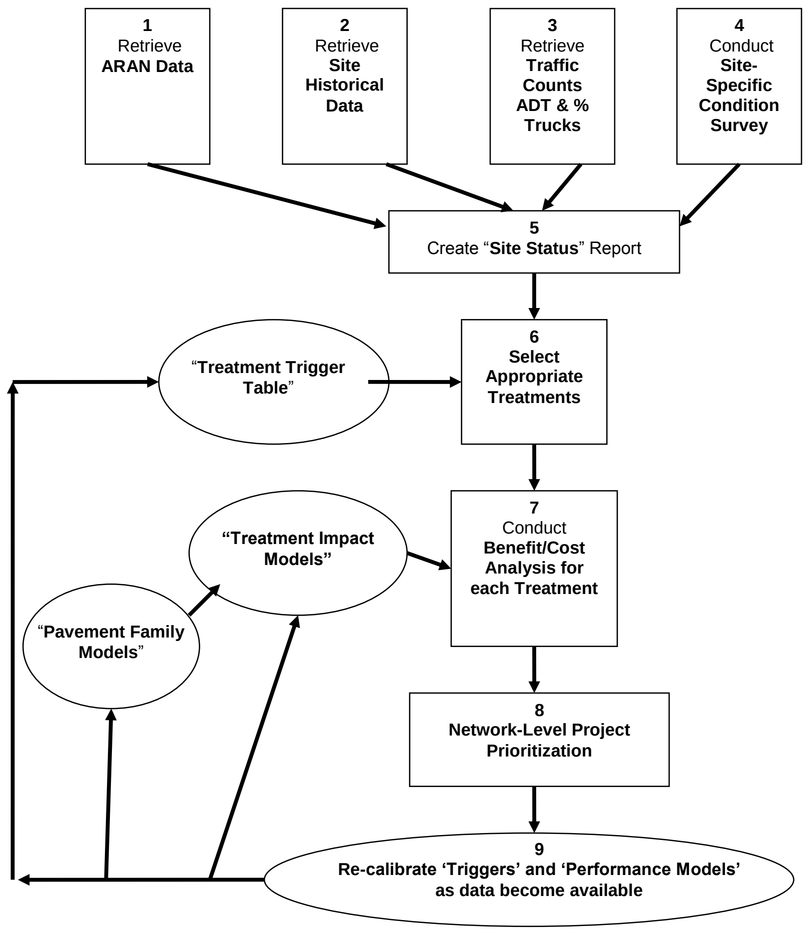


Fig. 1.1 – Procedural steps for implementing a modified pavement management process (Zimmerman et al. 2011).

This information is taken from the updated AASHTO Guide to Pavement Management (Zimmerman et al. 2011) that MoDOT strongly recommended to the project team. Based on the AASHTO Guide, the following is the procedure that a MoDOT Pavement Engineer or Specialist would use for implementing the *modified pavement management flowchart* (Fig. 1.1). The procedure would be followed for a given proposed road maintenance/preservation/rehabilitation project. The word "retrieve" is used to emphasize that the data, models, and tables to be used would already exist:

Step 1- Retrieve annual road condition survey (e.g. ARAN) data

Step 2- Retrieve site historical data: e.g. materials, thicknesses, subgrade soil, drainage, climate, construction records

Step 3- Retrieve traffic information: Annual Average Daily Traffic (AADT) and percentage trucks, or Annual Average Daily Truck Traffic (AADTT)(Commercial Truck Volume)

Step 4- Conduct a site-specific condition survey (visual, coring, non-destructive testing)

Step 5- Combine information from steps 1 through 4 into a "Site Status". Identify the roadway as a certain "Pavement Family" type (see Table 1.1 for potential families; the actual families determined in Task 2 are presented later)

Step 6- With "Site Status", enter appropriate "Treatment Trigger Table" and select several alternate treatments (Table 1.2) appropriate for the assigned Family

Step 7- With the appropriate "Treatment Impact (Performance) Models," conduct a cost effectiveness analysis for each potential appropriate treatment

Step 8- Using the calculated cost effectiveness of all treatments and all projects, conduct a network-level (county, region or state-wide) project prioritization list. Project prioritization could be based on other considerations in addition to benefit/cost

Table 1.1 – Potential definitions of Pavement Families in Missouri in a mature PMS

Flexible:
▪ < 7 in. Full-depth asphalt[1]
▪ ≥7 in. Full-depth asphalt[1]
Composite:
• Asphalt over concrete
Concrete:
▪ JPCP, 15 ft joint spacing
▪ JRCP, 61.5 ft joint spacing
▪ CRCP
▪ Bonded concrete overlay over concrete

▪ Unbonded concrete overlay over concrete
▪ Concrete over asphalt (whitetopping)

[1] may include nominal unbound granular base

[2]Tasks 1 and 2 created fewer Families, which are presented later in this Volume

Table 1.2 – Example of pavement treatment types used in Missouri (not limited to MoDOT)

Pavement Treatment Types
▪ Crack sealing/filling and joint sealing
▪ Chip sealing, fog sealing, scrub sealing, scratch sealing
▪ Micro-surfacing, slurry sealing, onyx slurry sealing
▪ Scratch and seal
▪ Ultra-Thin Bonded Asphalt Wearing Surface (UBAWS)
▪ Thin overlays: 1 ¾, 1 ¼ or 1-in.
▪ Mill & fill, mill & overlay (see above overlays)
▪ Asphalt Cold In-Place Recycling (CIR)
▪ Asphalt Hot In-place Recycling (HIR)
▪ Diamond grinding
▪ Load transfer retrofit & joint repair
▪ Partial/ full depth repair
▪ Whitetopping

Thus, Task 5 was involved with creating the trigger tables used in step 6 and creating an analysis scheme for step 7.

Fig. 1.2 shows the concept of the change in a given pavement's condition over time, and the optimum time for various interventions.

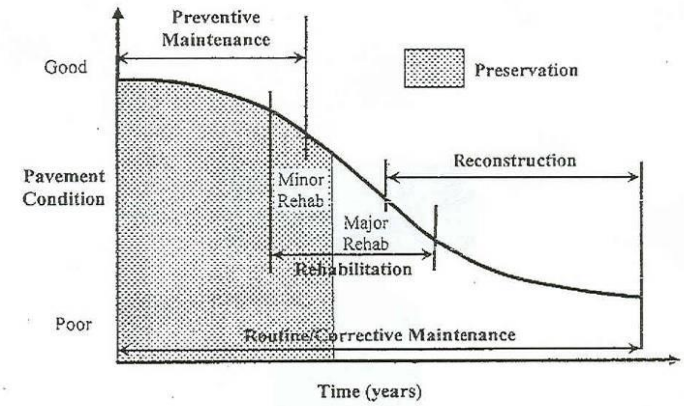


Figure 6-1. Relationship between pavement condition and different categories of pavement treatment (adapted from Peshkin et al. 2007).

Fig. 1.2 – Conceptual plot of pavement condition vs. time (Zimmerman et al. 2011).

"*Pavement Preservation*" involves a set of practices that extends pavement life. The practices include *Preventive Maintenance*, *Minor Rehabilitation*, and *Corrective Maintenance* (Peshkin et al. 2011a). As can be seen from Fig. 1.2, there is some overlap of these practices in regard to definitions. For the purposes of this study, "*Minor rehabilitations*" are *programmed* non-structural enhancements that occur in the early-to-middle years of a pavement's life when serviceability/ride issues become apparent. Examples are thin hot mix asphalt (HMA) and cold mix asphalt (CMA) overlays and mill-and-overlays. MoDOT maintenance forces sometimes call these "Treatments", as discussed in the Task 1 report. *"Preventive Maintenance"* includes *programmed* activities that preserve the system, retard future deterioration, and maintain or improve functional condition without adding significant structural capacity. These strategies are applied early in the deterioration-time curve before significant structural deterioration. MoDOT maintenance forces sometimes call these "Preventive Treatments". Examples presented in MoDOT's Engineering Policy Guide (EPG) are crack sealing/filling, joint sealing, and surface treatments (chip seals, scrub seals, scratch-and-seals, fog seals, onyx seals, spot-seal coating, UBAWS, and micro-surfacing) (MoDOT 2014). *Corrective Maintenance* is *non-programmed* work performed in response to unforeseen development of deficiencies that impact safety or operational functionality. MoDOT maintenance forces sometimes call these "Reactive Treatments". An example is partial patching. As can be seen from Fig. 1.2, there is some overlap in the timing of these arbitrarily-defined actions and what they are named, especially thin overlays.

Fig. 1.3 shows the concept of comparing different treatment strategies at different intervention times with the subsequent consequences for a given route. The curves represent models; the initial or original curve would be from actual historical data for the route, or, if not enough history for that route is available, a Family model (curve) would be substituted. Each of the other curves would be "Treatment Impact Models". Traditionally, state DOTs divide Pavement Families into Concrete (perhaps several families, based on design features or traffic volume), asphalt-on-concrete (Composites)[perhaps several families based on thickness or traffic volume], and Asphalt (perhaps several families based on thickness or traffic volume, or presence of granular base, and thickness of base). For example, in the present study, working with minor routes, essentially all composite pavements in the dataset were Jointed Reinforced Concrete Pavements (JRCP) at 61.5 ft length, so there was only one family in this category. Most minor route asphalt pavements did not have a history of construction, thus details of asphalt thickness and presence of significant granular base were not available, so all asphalt pavements were called "Full-Depth Asphalt". Previous studies encountered the same problem (MoDOT 2002).

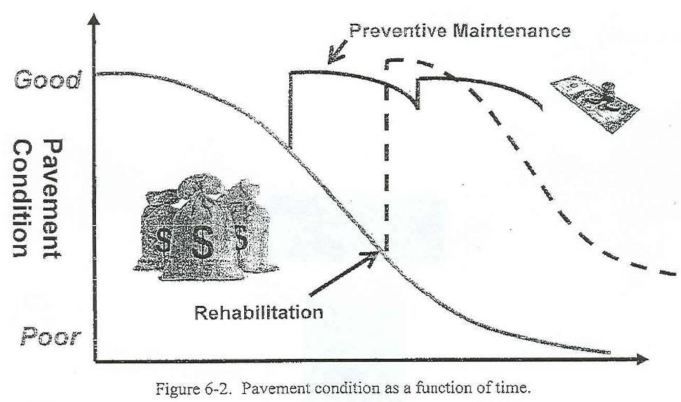


Fig. 1.3 – Conceptual plot of pavement condition vs. time with different interventions (Zimmerman et al. 2011).

1.3 Causes of Deterioration

It is imperative that in order to make proper selection of treatments, the causes of deterioration of pavements is understood. The following causes are in addition to existing pavement condition prior to treatment and condition after the treatment.

1.3.1 Asphalt Pavement Deterioration

1.3.1.1 Traffic

Traffic is associated with load-related distress (e.g. rutting of any of the pavement layers and fatigue cracking) and surface polishing (loss of friction).

1.3.1.2 Environment and Aging

Age-hardening of asphalt leads to weathering/raveling and block cracking. Thermal-related movement may cause thermal (transverse) cracks.

1.3.1.3 Materials

Poor mix characteristics can lead to plastic deformation of the mix (shoving, corrugations, asphalt rutting), bleeding, and stripping.

1.3.1.4 Moisture

Moisture infiltration can lead to further deterioration of cracks and cause increased roughness. Infiltrated moisture can cause subgrade softening, leading to longitudinal cracks at the pavement edge, potholes, and subgrade rutting.

1.3.2 Concrete Deterioration

1.3.2.1 Traffic

Traffic is associated with load-related distress (e.g. mid-panel cracks for jointed pavements, punchouts for CRCP; pumping, faulting, and corner breaks) and surface polishing (loss of friction).

1.3.2.2 Environment and Materials

The interaction of the pavement's environment and specific materials can lead to durability cracking (D-cracking) and alkali-silica reactivity (ASR). Even if ASR aggregates do not originate in the state, these materials can be transported from other states. Also, the environment can cause oxidation of any sealed joints which can allow water infiltration.

1.3.2.3 Construction

Poor quality construction can cause problems such as scaling, map cracking, and longitudinal cracking.

1.3.2.4 Incompressible Materials

Incompressibles lodged in joints can cause joint spalling.

1.3.2.5 Moisture

Moisture infiltration can lead to further deterioration of cracks and cause increased roughness. Infiltrated moisture can cause subgrade softening, leading to pumping, faulting, and corner breaks.

1.4 Factors Affecting Pavement Treatment Service Life

It has been shown that the longevity of pavement maintenance treatments depends upon:

- Original pavement type
- Layer thicknesses
- Base characteristics, including internal drainage
- Specific design features
- Subgrade type
- Condition prior to treatment
- Initial condition after treatment
- Quality of treatment
- Climate
- Accumulated traffic, especially truck traffic
- Interim maintenance procedures

- Surface age

Some additional descriptions can represent some of the above factors. As an example, “pavement functional classification” may be able to be used as a surrogate for thickness, base characteristics, design features, and quality of treatment. “Surface age” could represent traffic and environmental effects.

1.5 Objective

The objective of Task 5 was to produce Trigger Tables/Decision Trees and the Treatment Candidate Selection Process.

1.6 Scope of Work

Task 5 involved the creation of Treatment Trigger Tables and a Treatment Candidate Selection Process, keeping in mind the existing MoDOT situation:

- Present functional roadway classifications
- Combination of electronic and manually-accessed data sources
- Policies in the Pavement Maintenance Direction report
- Maintenance decision tree in the EPG
- Formalized condition evaluation methods limited to International Roughness Index (IRI) and Pavement Surface Evaluation and Rating (PASER)(Walker et al. 2002a,b)
- District methods of maintenance programming (no statewide network analysis method of maintenance project ranking (Schofield et al. 2011))
- Past decision to abandon Deighton software dTIMS

A procedure was to be furnished to select appropriate treatments (design) including a treatment matrix showing the most appropriate applications for given specific site conditions (Step 6 Fig. 1.1) and to perform an Equivalent Annual Cost (EAC) or Benefit/Cost Analysis (BCA) or Remaining Service Life (RSL) Analysis (Step 7 Fig. 1.1) for each candidate treatment to ultimately recommend a specific treatment (Zimmerman et al. 2011). The idea in using the trigger tables is to decide what optional treatments it will take for a given roadway segment to keep a Good road Good, move the rating from Poor into Good, or in an extreme case, from Poor-Unsafe to Poor-Safe. Deliverables are: 1) Trigger tables/Decision Trees, and 2) cost-effectiveness methodology (roadway project specific-only). The sub-tasks are listed below:

1. Sub-task 5A: Procure laboratory equipment and AASHTOWare Pavement ME Design software
2. Sub-task 5B: Conduct literature search
3. Sub-task 5C: Engage in discussions with MoDOT to obtain information about pavement types, treatment types, selection criteria, mixes, and past history
4. Sub-task 5D: Conduct treatment option analysis using AASHTOWare
5. Sub-task 5E: Conduct mixture testing and analysis

6. Sub-task 5F: Create a draft manual of treatment trigger tables and cost evaluation procedures
7. Sub-task 5G: Review the draft Task 5 manual and complete a final version. Sub-task 5G will not be included as a written section in this report, rather, it is by nature an action item.
8. Sub-task 5H: Provide training of MoDOT personnel in use of the product (trigger tables and benefit/cost calculations). Sub-task 5H will not be included as a written section in this report, rather, it is by nature an action item.

2 SUBTASK 5A: PROCURE LABORATORY EQUIPMENT AND AASHTOWARE SOFTWARE

Purchase or design and fabrication of the following was completed: Asphalt Mix Performance Tester (AMPT), Applied Pavement Technology (APT) Hamburg Loaded Wheel Tester and digital upgrade, four conditioning ovens with support shelves, gyro mold spacers, gyro mold modification, core drill permanently mounted, core holding jig, and core holding saw jig. Unfortunately, after the first round of testing, the AMPT compressor was found to be faulty, so delays were encountered until the unit was replaced by the vendor. Additionally, as the project evolved, it was decided to try to replace some types of testing (dynamic modulus) with a more applicable testing method via the Texas Overlay device. Unfortunately, the Texas device that was delivered was recalled due to design deficiencies, and a re-configured replacement had to be ordered and was delivered too late to be used. Also, recently the AMPT power supply failed and a replacement had to be ordered and installed. However, useful data was generated and is reported herein.

3 SUB-TASK 5B: CONDUCT LITERATURE SEARCH

Numerous state DOT Pavement Management Systems (PMS) were reviewed in an effort to discover the types of data necessary for creating treatment trigger tables/decision trees. Those DOTs reviewed were Mississippi, Louisiana, Colorado, Virginia, South Dakota, Nebraska, North Carolina, Arizona, Pennsylvania, Minnesota, North Dakota, Oklahoma, Oregon, Washington, Texas, and Missouri. Several are discussed below. However, most of the information from the literature search is reported and analyzed in the applicable chapters, most notably Chapter 7.

3.1 Mississippi DOT

George (2000) authored a report about the prediction models used by the Mississippi DOT's PMS, which were initiated in 1986. The report describes the PMS database and modeling data, particularly the partitioning of roadways into homogenous sections. Data collected for each section in the database were consistent with the discussion from the AASHTO guide (Zimmerman et al. 2011). The 26 pavement models in the report were based on a composite condition index that included IRI, and various distress measures. The models included subgrade characteristics. Pavement types were divided into five families. Data collected included pavement types, thicknesses, joint and reinforcement information, percent trucks, age, maintenance type, IRI, and 11 types of distress, along with severity and extent of those distresses.

3.2 Louisiana DOT

In 2009, Khattak et al. issued a report addressing performance models used in Louisiana's PMS. Phase I of the accompanying project assessed the data collection for the PMS. The authors noted good pavement distress data were available beginning in 1995, and that data were collected continuously for 0.1-mile long segments. The study also found that maintenance and rehabilitation data were recorded but not accessible through the PMS. In addition, various location-referencing systems were used by Louisiana's DOT. The authors noted that various types of distress indices were collected, and recommended expanding the types of distress to be more specific (e.g. alligator cracking, block cracking, etc.) rather than use the term "random cracking." IRI and 11 types of distress data were collected, along with distress severity and extent.

3.3 Colorado DOT

Colorado's system (Colorado 2011, 2012), initiated in the late 1980's, had pavement families that were comprised of four pavement types and five traffic levels. Climate was included as a variable in partitioning of homogenous sections as well as pavement thickness. The state route system was divided into 3700 segments (homogeneous sections). Data collected included pavement types, thicknesses, IRI, and four types of distress, along with severity and extent. The distresses were used to calculate individual distress indices. Each homogenous section had several condition index deterioration models (curves) associated with it (e.g. for asphalt: IRI, rutting, transverse cracks, longitudinal cracks, and fatigue cracks). The types of models were site-specific; when insufficient data was available to plot a site-specific curve, family models were regressed from similar sections to act as surrogates. Periodically, collected data was fed into software that calculated Remaining Service Life (RSL) for each distress. The lowest RSL of the five individual distress RSLs was used for each segment. Commercially available software calculates the benefit-cost (B/C) for each possible treatment strategy for each route. At the network level, the software weighted the RSLs for traffic volume, ranked the B/Cs at the network level, then chose the best strategy for each segment via an "incremental benefit-cost" method. Working down the list, the highest-ranked projects were chosen until the budget was exceeded. The resurfacing list was given to the Regions which had some leeway in actually allocating which routes received funding, based on local constraints.

3.4 Virginia DOT

Virginia's system (McGhee et al. 1991), initiated in the early 1980's, included five pavement families. Data collected included roughness, rut depth, patching, various crack measurements (distress severity and extent was included), truck traffic, and age since last treatment.

3.5 South Dakota DOT

South Dakota's system (South Dakota 2012), begun in 1977, had 12 pavement families. IRI and 11 types of distress data were collected, along with distress severity and extent. Distress and performance models numbered 168. Table triggers were based on condition indices, one of which was IRI. Projects were sorted by the "incremental B/C" method via computer software.

4 SUB-TASK 5C: ENGAGE IN DISCUSSIONS WITH MODOT TO OBTAIN INFORMATION ABOUT PAVEMENT TYPES, TREATMENT TYPES, SELECTION CRITERIA, MIXES, AND PAST HISTORY

The Task 5 team met with or held telephone/email conversations with a number of MoDOT personnel from different divisions one-on-one in regard to choice of mix designs, pavement maintenance policies, lab equipment, and subgrade soils data: Construction and Materials (John Donahue, Joe Schroer, Jason Blomberg, Paul Denkler, Dan Oesch, Rob Massman, Jeff Huffman, Donna Hoeller, Leslie Wieberg, Mike Fritz, and Kevin McLain), Planning (Jay Whaley), and Maintenance (Mike Dunseth, Todd Miller, Jason Sommerer, Brad Brown, Jason Schafer, Kenton Bohon, Charles Schroyer, Dale Baumhoer, Ken Strube, Mark Buscher, Mike Belt, and Joe Moore). From these discussions, decisions were made in choosing mix types to study in sub-task 5E.

5 SUB-TASK 5D: CONDUCT TREATMENT OPTION ANALYSIS USING AASHTOWARE

During the conduction of real-world experiments, it is difficult if not impossible to hold all but one variable constant. Thus, software simulations are used to accomplish this level of control. The state's geologic areas/soil associations and climate variables were examined, leading to a first pass through the AASHTOWare software (Asphalt Concrete - Overlay Over Asphalt) for 208 pavement scenarios for 1-in. surface leveling (section 402) mixes. Variables that were included are shown in Table 5.1.

Table 5.1 - AASHTOWare mix analysis variables and levels for surface leveling mixtures

Variable	Levels		
Overlay Material Quality	good	poor	----
Existing Condition	fair	very poor	----
Existing Thickness	3 in.	6 in.	----
Existing Materials Quality	good	poor	----
Subgrade Quality	A-1-a	A-7-6	----
AADTT, 2 way	80	700	----
Climate	NW	Central	SW

Also, MoDOT's Mechanistic-Empirical Pavement Design Guide (MEPDG) local calibration constants for subgrade rutting, IRI, and asphalt rutting as per the MEPDG calibration report (2009) have been applied to the software.

Table 5.2 shows the details of the Overlay Material and Existing Material input mix characteristics. The "Good" mix was based on meeting MoDOT's 2015 section 402 specification on volumetrics and percent passing the #200 sieve (P200). The "Poor" mix featured a lower Voids Filled Asphalt (VFA) and a greater passing #200 content, which stretch the values to the maximum allowable, simulating what may happen in the field. However, predicted life proved to be insensitive to P200 within the range attempted.

Table 5.2 - Overlay and Existing Material input mix characteristics - surface leveling mixtures

Characteristic	Good	Poor
VMA, %	14.0	14.0
Effective binder content (P_{beffv})	10.5	8.4
Air voids, %	3.5	5.6
VFA, %	75	60
% Passing #200	5	12

Table 5.3 presents subgrade quality details of the "Good" and "Poor" conditions which were shown to occur in Missouri, as discussed in the Task 1 report. Most of the 12 AASHTO soil classifications are represented in Missouri, including A-1-a and A-7-6 soils. Thus, these two were used in the analysis to represent the best and worst soils. Resilient modulus values for a

given soil are a function of soil type, moisture content, and stress state, and a granular soil's modulus can get fairly high for thin pavements as a result of greater confining stress.

Table 5.3 - Good and Poor subgrade characteristics

Characteristic	Good	Poor
Classification	A-1-a	A-7-6
Liquid Limit	10	55
Plasticity Index	2	32
P200 (%)	8.7	79
Resilient Modulus (psi)	35,800	5475

Table 5.4 shows the three climates used for the analysis, based on weather data derived in Task 1. Weather stations (real and virtual) were used for locations in the northwest, central, and southeast parts of the state.

Table 5.4 - Climate information

Parameter	Northwest	Central	Southeast
Weather stations	Kansas City-Des Moines	Jefferson City	Poplar Bluff-Blytheville
Latitude	40.35	38.567	36.196
Longitude	-94.83	-92.183	-89.661

Traffic levels in the Task 2 models were less-than-400, 400-750, 750-1700, and 1700-3500 AADT (one-way). For the lowest and highest traffic levels, assuming 10% truck traffic, AADTT (two-way) would be 80 and 700. These AADTT levels were chosen for the analysis. The default traffic conditions of two-lane, 95% trucks in the design lane, and 60 mph were assumed.

The existing conditions of the pavement were chosen based on how deteriorated the condition of pavement may be when treated. Two levels were chosen as "Fair" and "Very Poor", reflecting the ability of maintenance forces to intervene.

Existing pavement thicknesses were varied as 3- or 6-in., based on actual thicknesses encountered on low volume minor roads cored in Task 4 field coring and non-destructive evaluation (NDE) work.

Other values for running the AASHTOWare software that were held constant are shown in Table 5.5.

Table 5.5 - Input held constant - AASHTOWare analysis of factors affecting pavement life

Factor	Value
Overlay thickness (surface leveling)	1 in.
Initial IRI (IRI_o)	86 in./mile mostly; others were 55, 100, and 126 (based on Task 2 data)
Binder grade	PG 64-22
Granular base thickness	4 in.
Granular base material	Crushed stone
Granular base material characteristics	Program default
Subgrade soil characteristics	Program default
Traffic distribution, growth, etc. characteristics	Program default
Terminal IRI (IRI_t)	140, 170 in./mile
Terminal total deformation	3/8 in.
Other terminal conditions	Program default
Climate characteristics (within a given weather station)	Program default
Binder and mix characteristics	Program default

The results of the AASHTOWare analysis are shown in Figs. 5.1 to 5.8. The condition designation follows:

- First character: overlay quality, either G or P; G = Good, P = Poor
- Second character: existing pavement condition prior to overlay, either F or V; F = Fair, V = Very Poor
- Third character: existing pavement thickness; either 3 or 6 in.
- Fourth character: existing mix quality, G or P; G = Good, P = Poor
- Fifth character: subgrade quality, G or P; G = Good, P = Poor
- Sixth character: climate in Missouri; either NW, C, or SE; NW = northwest, C = central, SE = southeast
- Seventh characters (set of numbers): AADTT, either 80 or 700
- Eighth characters (set of numbers): initial IRI: either 55, 86, 100, or 126 (if none, then is 86)

For example, GF3GGNW700 means *Good overlay mix, Fair existing pavement condition, 3 in. existing asphalt thickness, Good existing mix, Good subgrade, NW Missouri,* and *700 AADTT*. All initial IRIs were 86 unless there is a 55 or 100 at the end of the designation. NW700 conditions were chosen as the default for comparison. The dashed line in each figure denotes the life in years of the default set of conditions for each figure. For instance, in Fig. 5.1 the default set of conditions is GF3GGNW700-86 which had a predicted life of 14 years. All other conditions are compared to 14 years.

.

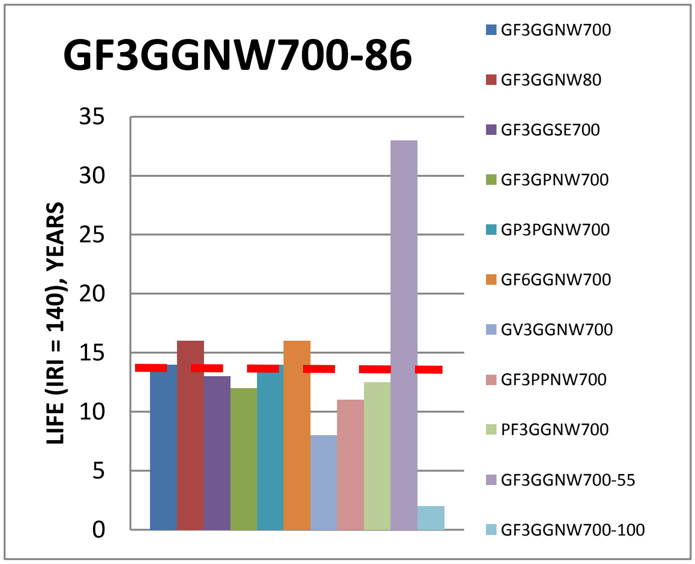


Fig. 5.1 – Comparison of variables' effect on default condition GF3GGNW700-86.

As an example, keeping thickness constant (3 in.), Fig. 5.1 shows the effects of the variables on IRI (140) life. As can be seen, loss or gain in longevity due to each of the variables compared to the GF3GGNW700-86 circumstance ranged from 0.0 to 19 years. The more important variables were IRI_0, existing roadway condition, AADTT, thickness, and subgrade, followed by climate and overlay quality. IRI_0 had a large effect: when IRI_0 was varied from 86 to 55 or 100, overlay life changed by +19 and -12 years, respectively.

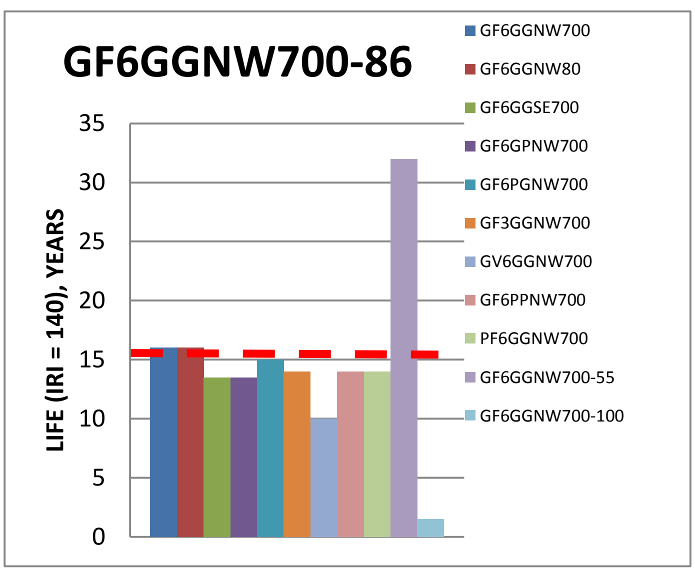


Fig. 5.2 – Comparison of variables' effect on default condition GF6GGNW700-86.

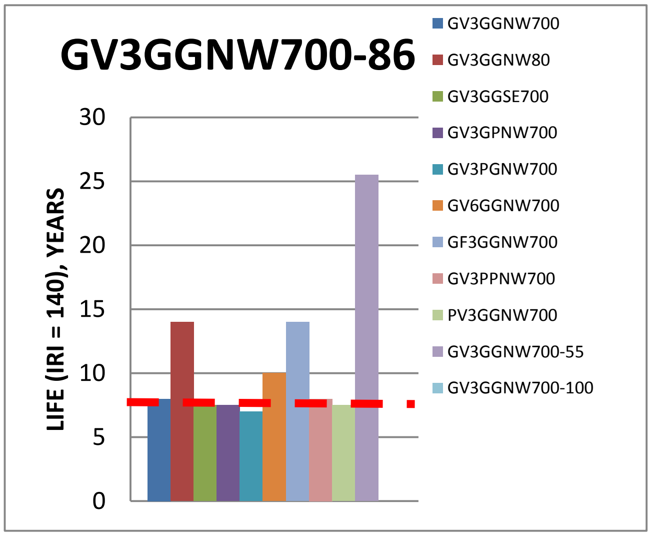


Fig. 5.3 – Comparison of variables' effect on default condition GV3GGNW700-86.

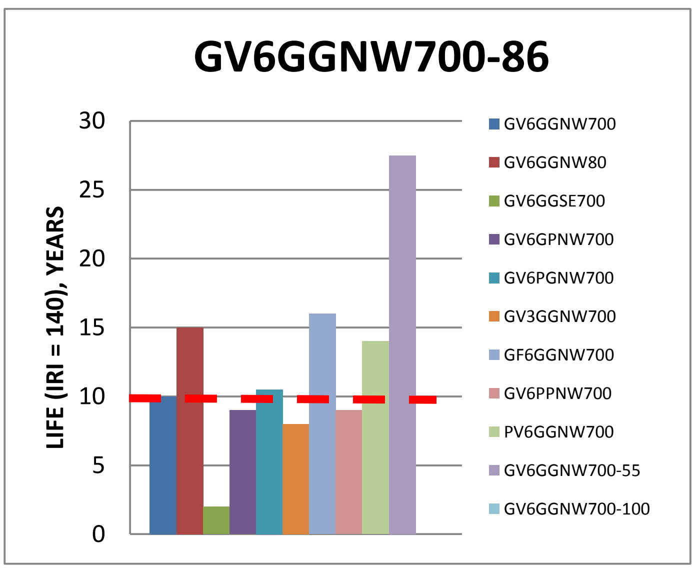


Fig. 5.4 – Comparison of variables' effect on default condition GV6GGNW700-86.

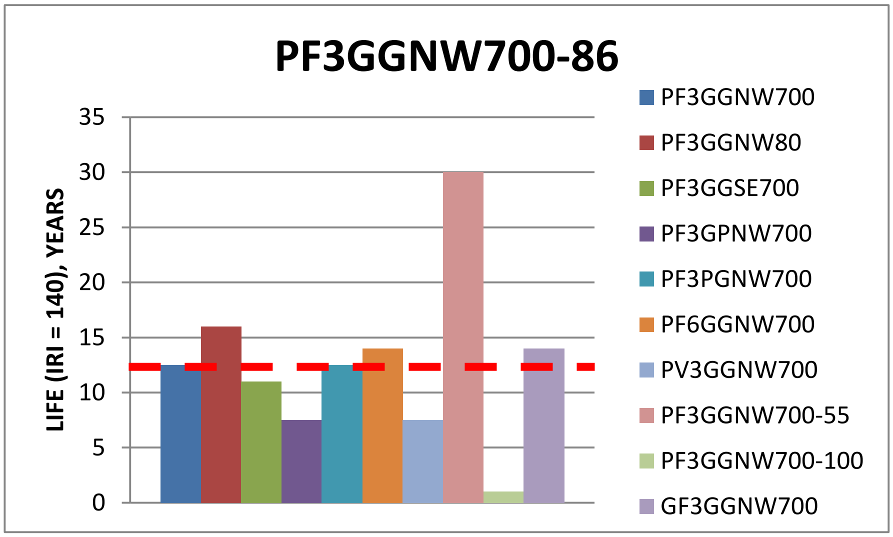


Fig. 5.5 – Comparison of variables' effect on default condition PF3GGNW700-86.

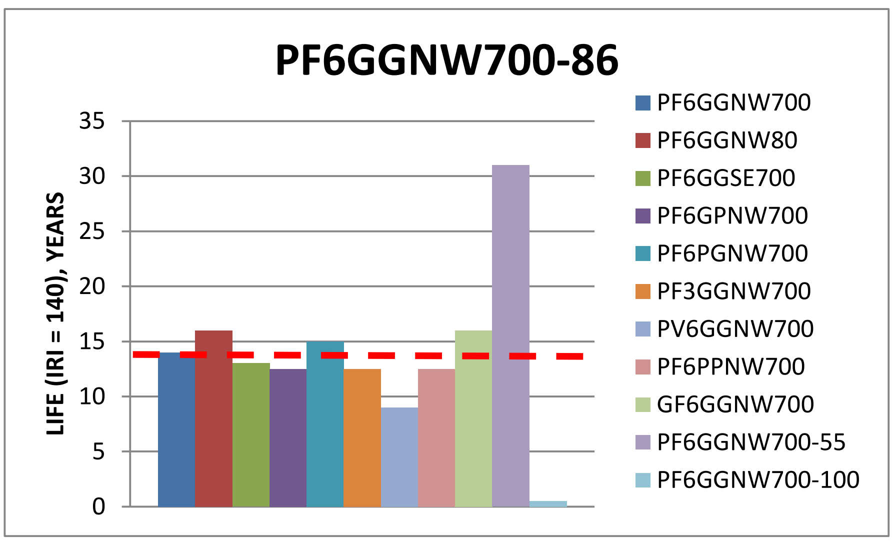


Fig. 5.6 – Comparison of variables' effect on default condition PF6GGNW700-86.

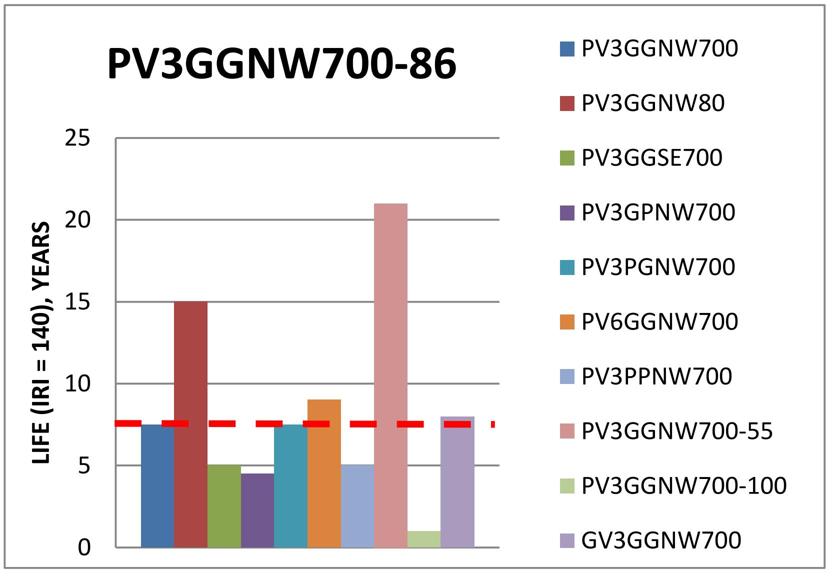


Fig. 5.7 – Comparison of variables' effect on default condition PV3GGNW700-86.

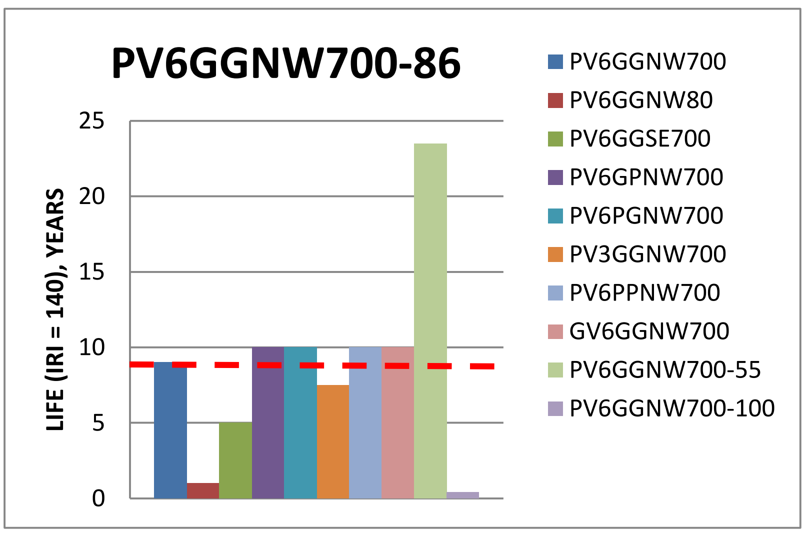


Fig. 5.8 – Comparison of variables' effect on default condition PV6GGNW700-86.

Overall, for a terminal IRI = 140, looking at the Missouri climates, subgrades, truck traffic levels, qualities of overlay mix, pavement conditions prior to overlay, and initial IRIs after treatment, the 1-in. overlays were predicted to last an average of 12.5 years (range 0 to 33 years). The extreme ends of the range reflected the extreme limits of initial overlay IRI; starting very smooth lengthens life and vice-versa. A summary of average, minimum, and maximum predicted changes (losses or gains) in years of life are shown in Table 5.6; each row's data is relative to the default condition. As can be seen, the most significant effect is initial IRI, followed in order by existing condition, AADTT, climate, subgrade, existing thickness, and qualities of new and existing overlay materials.

Table 5.6 – Effect of variables on AASHTOWare change in predicted lives of 1-in. overlays

Default Condition	ADTT	Climate	Subgrade	Existing Mix	Existing Thickness	Existing Condition	Overlay Quality	IRIo 55	IRIo 100
GF3GGNW700-86	2	1	2	0	2	6	1.5	19	12
GF6GGNW700-86	0	2.5	2.5	1	2	6	2	16	14.5
GV3GGNW700-86	6	0.5	0.5	1	2		0.5	17.5	8
GV6GGNW700-86	5	8	1	0.5	2		1	17.5	10
PF3GGNW700-86	3.5	1.5	5	0	1.5	5		17.5	11.5
PF6GGNW700-86	2	1	1.5	1	1.5			17	13.5
PV3GGNW700-86	7.5	2.5	3	0	1.5		0.5	13.5	6.5
PV6GGNW700-86	6	4	1	1			1	14.5	9
avg=	4.0	2.6	2.1	0.6	1.8	5.7	1.1	16.6	10.6
min=	0.0	0.5	0.5	0.0	1.5	5.0	0.5	13.5	6.5
max=	7.5	8.0	5.0	1.0	2.0	6.0	2.0	19.0	14.5

Regression analyses of the AASHTOWare analyses output were done as another way to determine the input variables that were important to pavement longevity in terms of time to reach an IRI of 140 (starting at 86). The best model (highest adjusted-R^2) for life (years) to reach an IRI of 140 (adjusted-R^2 = 0.8684) included the following significant variables, in order of magnitude of effect: 1) Accumulated Truck Traffic 2) Existing Condition 3) Subgrade Quality and Existing Thickness, and 4) Overlay Quality followed closely by Climate.

Additionally, three bituminous plant (BP-1) mixes have been evaluated via the AASHTOWare software. With different inputs of IRI_0, subgrade quality, AADTT, and volumetrics, conclusions were that volumetrics seem to impact predicted performance the most (a reduction in VFA from 75 to 60), with the fatigue cracking prediction the most sensitive performance criteria.

6 SUB-TASK 5E: CONDUCT MIXTURE TESTING AND ANALYSIS

In regard to pavement treatment evaluation, longevity of various treatments must be predicted. Three approaches were followed in parallel. One approach, applicable to all treatment types from overlays to a variety of surface treatments, was to search the literature to garner other state DOTs' and other agencies' experiences with treatment longevity. A second approach was to generate treatment lives from MoDOT historical pavement data. The third approach, the subject of Task 5E, was to perform laboratory testing of HMA mix types in order to use results of performance testing such as Hamburg Loaded Wheel rutting/stripping characteristics and Tensile Strength Ratio (TSR) to assess the effect of mix characteristics on rutting and stripping. As the project evolved, it was decided to try to replace some planned types of testing (e.g. dynamic modulus) with a more applicable testing method for maintenance overlay type of mixes via the Texas Overlay device.

The general approach for mix selection was to narrow the scope of HMA mix types to be evaluated to those that would be used for maintenance on minor routes. After discussions with Paul Denkler, Jason Blomburg, and Joe Schroer, it was decided to eliminate Superpave and BP-3 mixes and concentrate on surface leveling (SL) and BP mixes. Because SL and BP-2 mixes are virtually the same in many cases, the final experimental design called for BP-1 and SL mix types.

Two levels of quality (Good and Marginal) per mix type were evaluated to give a range of behavior in performance testing. "Good" means high quality aggregate, proper volumetrics, proper binder content, proper dust/effective binder ratio, lack of deleterious materials, and so forth. "Marginal" relates to these attributes being barely approved in design and possibly even worse as-produced. All mix designs approved by MoDOT's field office in 2011 of surface leveling (SL), BP-1, BP-2, and bituminous base (BB) were examined as well as aggregate quality records. After discussions with Joe Schroer and one knowledgeable contractor, two aggregate sources (formations/ledges) were chosen. The Marginal aggregate source [Capitol Quarries, Rolla quarry, Jefferson City Dolomite, ledges #9 through #1J (multiple fractions)] and the Good aggregate source [Capitol Quarries, Sullivan quarry, Potosi Dolomite, ledge #1, (multiple fractions)] were identified and sampled. Three BP-1 mixes (Good, Marginal In-Specification (In-Spec), Marginal In-Tolerance (Out-of-Spec)) were tested. The binder for all mixes was a PG64-22 (one supplier).

Unfortunately, the MoDOT specifications for surface leveling and plant mixes have undergone a continuous series of changes since the project was conceived (2011). After the initial round of testing, MoDOT Research and Missouri S&T agreed to cease further testing until the effects of the changes were better defined and that the changes would settle down before testing resumed on the surface leveling mixes in a subsequent project.

Table 6.1 contains the BP-1 mix characteristics and MoDOT specifications.

Table 6.1 - BP-1 mix characteristics

Parameter	BP-1	BP-1 Good	BP-1 Marginal, In-Spec	BP-1 Marginal, Out-Spec
	Specification	**Design**	**Design**	**Design**
Aggregate Formation		Potosi Dolomite	Jefferson City Dolomite	Jefferson City Dolomite
Aggregate:				
Absorption, %	4.5% max.	1.4-2.0	3.0-4.1	3.0-4.1
LAA	55 max.	26	30	30
Micro Deval		9.6	21.5	21.5
Gradation % Passing:				
¾ in.	100	100	100	100
½ in.	85-100	98	98	98
#4	50-70	53	53	53
#8	30-55	30	31	38
#30	10-30	16	13	23
#200	5-12	5.0	7.0	12.0
Mixture:				
Natural sand, %		9.4	23.0	21.0
Shale	2.0% max	0	2.0	2.0
Clay, dispersed	3.0% max.	0	3.0	3.0
Binder, %		5.9	6.1	5.8
Effective binder, %		4.6	4.5	4.1
Effective binder by volume, %		10.7	10.2	9.5
Dust/binder		1.1	1.6	3.0
Air voids, %	3.5	3.5	3.5	1.7
VMA	13.5	14.2	13.7	11.2
VFA	60-80	75.3	74.5	84.5
TSR	70 min.	86	28	23
Tolerance/Action Limit:				
Binder, %	±0.3			-0.3
Passing #8, %	±5.0/10.0			+7.0
Passing #200, %	±2.0/4.0			+5.0

As can be seen, the Potosi Dolomite mix would be considered a good material for asphalt mixtures: relatively low absorption, low LA abrasion, low Micro-Deval, no deleterious materials, modest minus #200 content, low natural sand content, meets volumetric requirements, moderate dust/effective binder ratio, and a relatively high effective binder content by volume. The Jefferson City dolomite In-Spec mix met all requirements, but had inferior aggregate (high absorption, higher LA abrasion, high Micro-Deval), deleterious amounts of shale and clay dust at the maximum allowable by MoDOT specification section 1004, high natural sand content, greater dust/effective binder ratio, and lower effective binder content by volume. The Jefferson

City dolomite In-Tolerance Out-of-Spec mix was similar to the In-Spec Jefferson City mix, but with several mix components allowed to stray as if during production: the dust was increased to the specification maximum allowable, the gradation became finer, the binder content was reduced, which led to lower (out-of specification) air voids and VMA, and a high dust/effective binder ratio.

The mixes were subjected to Hamburg LWT and TSR testing. The results of the Hamburg testing for the Good, Marginal In-Spec, and Marginal Out-of-Spec mixes are shown in Figs. 6.1, 6.2, 6.3, and 6.4, respectively.

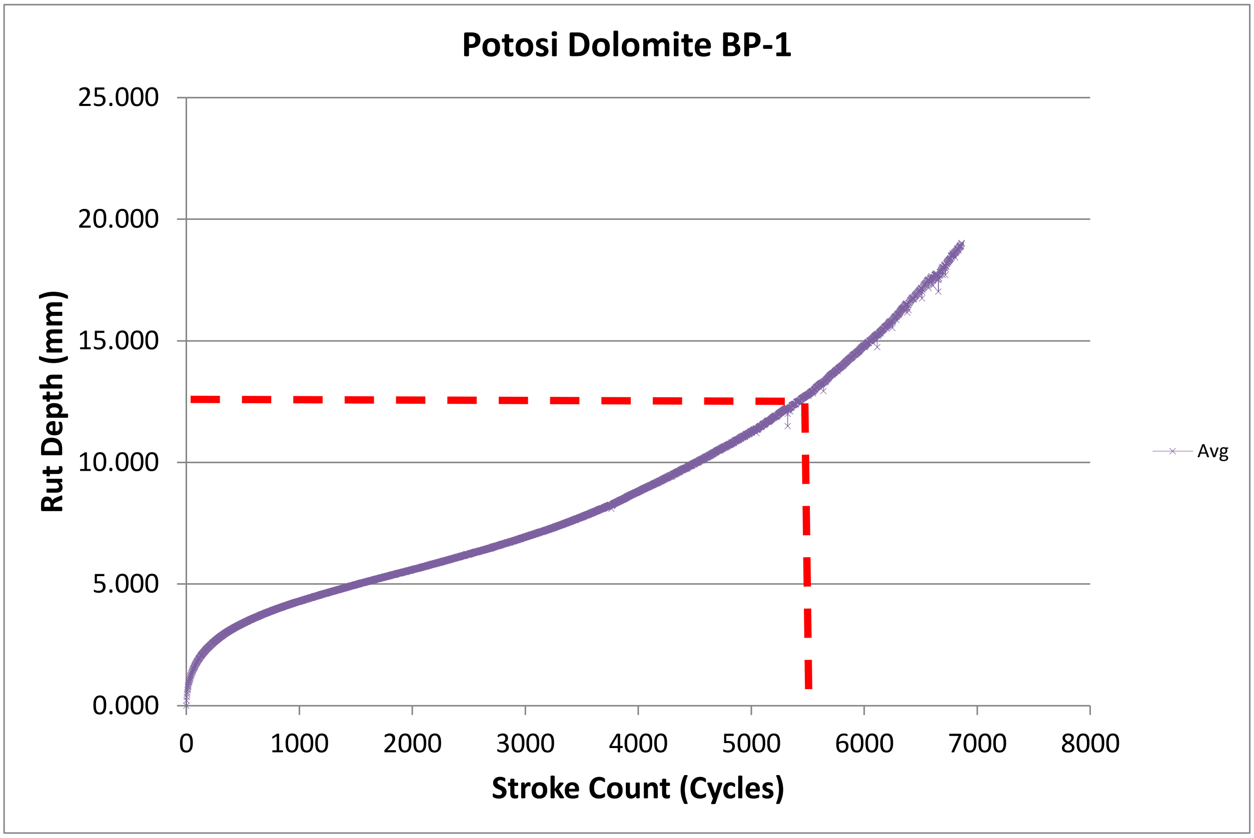


Fig. 6.1- Hamburg results for Potosi Dolomite mix, average of three curves.

Texas DOT (TXDOT) has had considerable experience with using Hamburg LWT results for mix approval, mix evaluation, and specification compliance. The Texas DOT criteria for limestone mixes with a non-modified binder PG 64-22 (similar to MoDOT's BP plant mixes) is equal to or less than 12.5 mm rutting at 5000 cycles. The Potosi (Good) mix met this requirement with about 5550 cycles at 12.5 mm rut depth. Very little stripping was observed by visual inspection (Fig. 6.2a). The TSR for the Potosi was 86%, well over the MoDOT section 401 minimum requirement of 70. For the Jefferson City Dolomite (JCD) In-Spec mix, the Hamburg results showed about 3040 cycles at 12.5 mm, failing the Texas DOT threshold. The TSR was 28%, badly failing MoDOT's section 401 specification. The visual exam showed a loss of matrix and considerable broken aggregate (Fig. 6.2b). As expected, the Jefferson City Dolomite (JCD) Out-of-Spec mix fared even worse than the In-Spec mix: the Hamburg results resulted in about 2440 cycles at 12.5 mm, failing the Texas DOT threshold. The TSR was 23%, badly failing MoDOT's section 401 specification. The visual exam showed a loss of matrix and considerable broken aggregate (Fig. 6.2.c).



Fig. 6.2.a- Potosi Dolomite *Fig. 6.2.b-JCD in-spec* *Fig. 6.2.c- JCD out-of-spec*

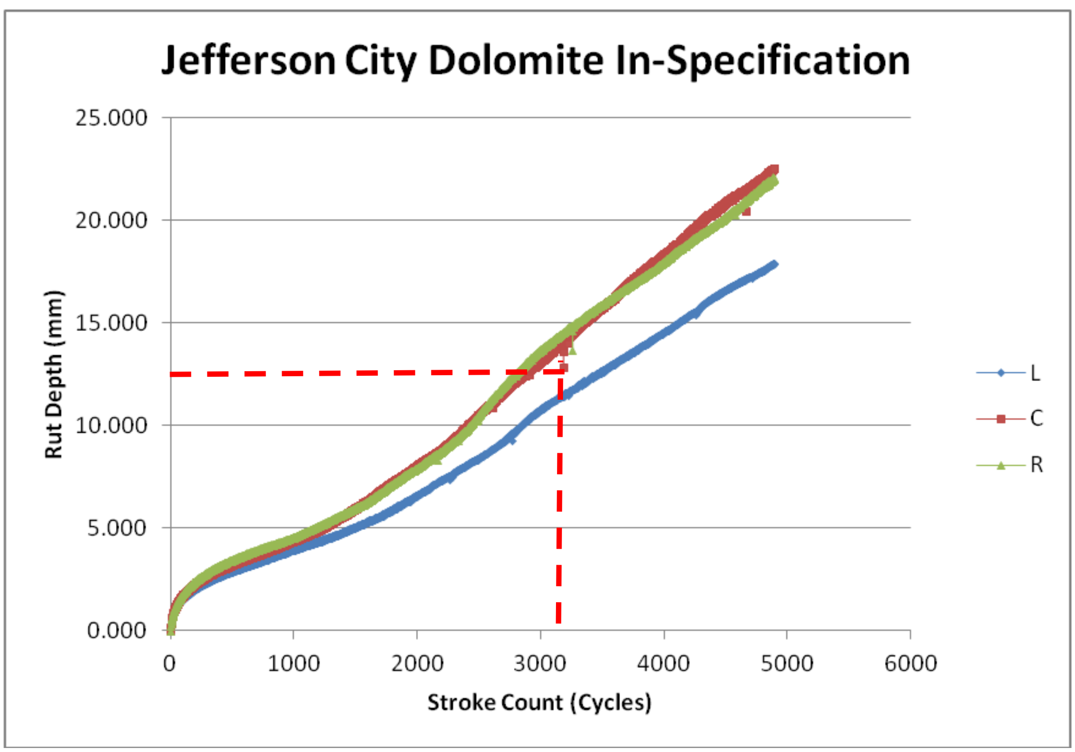


Fig. 6.3 – Hamburg results for Jefferson City Dolomite in-specification mix.

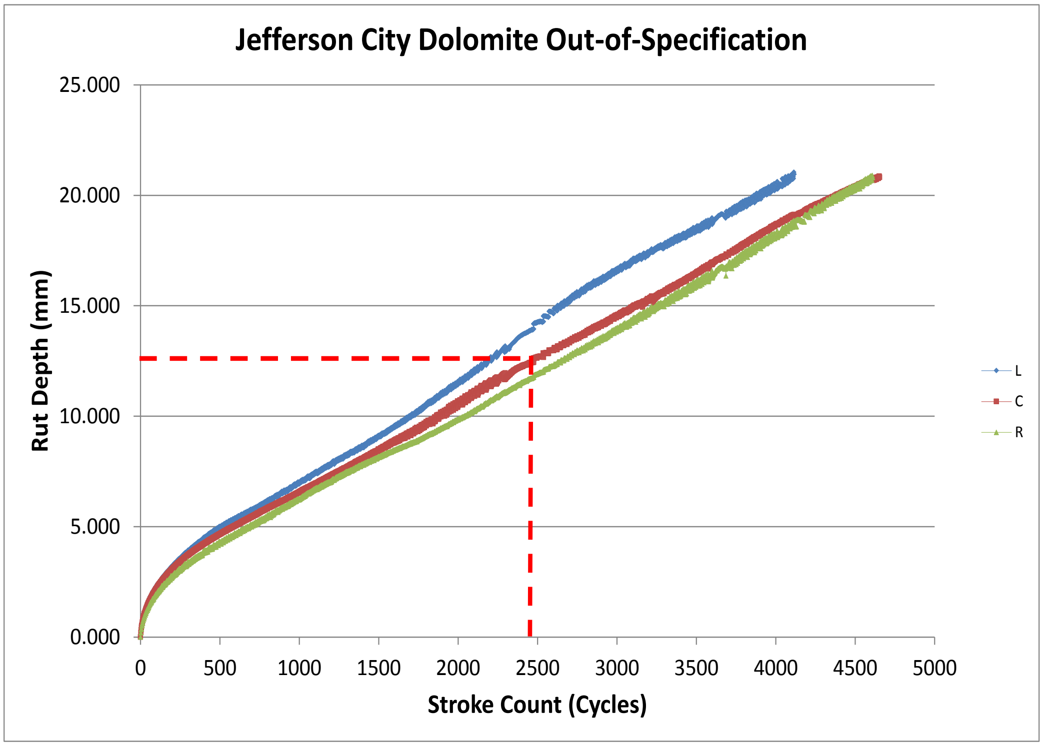


Fig. 6.4 – Hamburg results for Jefferson City Dolomite out-of-specification mix.

In Fig. 6.5 is shown the relationship of Hamburg cycles-to-12.5 mm rut depth to TSR. As can be seen, in this preliminary data, there is a direct relationship, as expected.

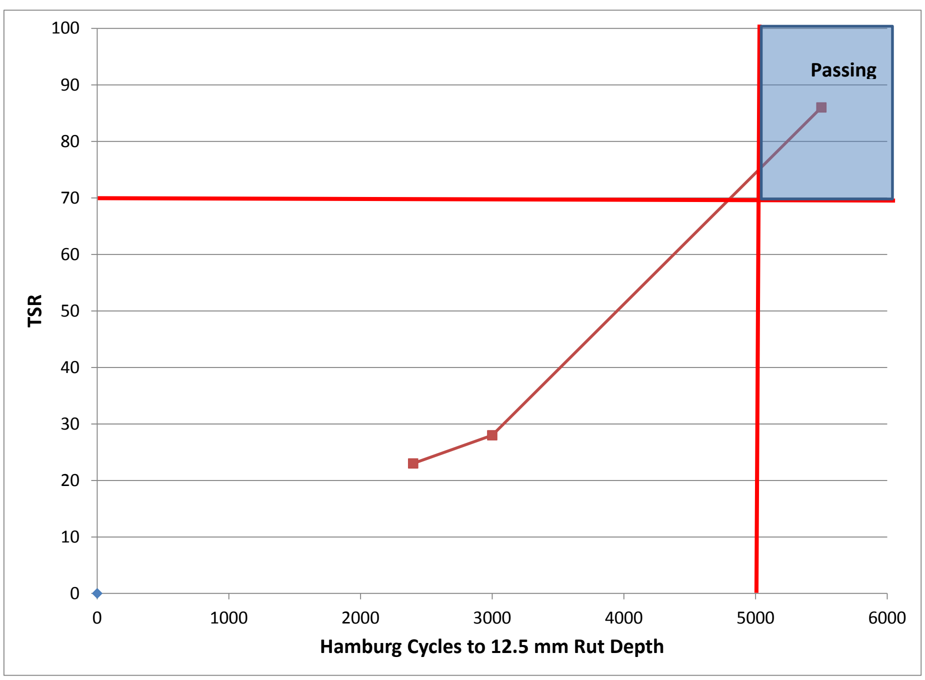


Fig. 6.5 - Relationship of Hamburg to TSR, all three mixes.

7 SUB-TASK 5F: CREATE A DRAFT MANUAL OF TREATMENT TRIGGER TABLE/DECISION TREES AND BENEFIT/COST PROCEDURES

Trigger tables were developed based on a combination of service life predictions from Sub-task 5B (experiences of other agencies), Sub-task 5C (MoDOT experiences and Task 2 models), Sub-task 5D (AASHTOWare data analysis), and Sub-task 5E (material laboratory testing). The chapter also includes a recommended method of cost evaluation procedures.

7.1 Factors Affecting Treatment Selections

Peshkin et al. (2011a, b), drawing from an extensive literature review of over 100 publications plus a survey of state DOT practices, listed 11 factors that affect treatment selection:

- Traffic
- Pavement Condition
- Climate and Weather
- Work Zone Restrictions
- Roadway Geometrics
- Experience with Treatment
- Availability of Good Quality Materials
- Availability of Specialized Equipment and Materials
- Environmental Considerations
- Expected Performance
- Available Funding/Cost

7.1.1 Traffic

The traffic level affects preservation treatment selection because it is a direct measure of loadings applied, which is important to treatment service life. Traffic stresses imparted to the pavement include vertical and horizontal shear as well as abrasive forces from repeated traffic applications and snowplows. Limited quantified data shows that as traffic levels increase, treatment lives drop 2-3 years.

Traffic level is also associated with roadway functional classification, which affects the appropriateness of certain treatments, i.e. some treatments are not appropriate for high volume traffic. For instance, the Utah DOT recommends chip seals and slurry seals for less than 7000 vehicles per day (vpd), micro-surfacing and hot-applied chip seals for 7000-15,000 vpd, and thin overlays for greater than 15,000 vpd. Traffic also affects access to the roadway to perform preservation activities (work zone duration restrictions), traffic disruptions, and traffic control and safety.

7.1.2 Pavement Condition

Not only is the overall condition of the pavement important, the specific distresses also impact the choice of proper treatment type. The treatment should be the right choice at the right time to address the right condition. The selection of the correct treatment depends on, among other factors, the location, extent, and magnitude of distress. Although IRI is the only universal measure of condition in use, it is felt that IRI gives an incomplete picture of pavement condition. Many times distress such as cracking begins but IRI stays relatively constant. As distress continues to increase, IRI begins to rise. By the time the IRI has increased significantly, the distress may have caused significant structural deterioration, well beyond what pavement preservation treatments can address. IRI is known as a "lagging indicator" for preventive maintenance, while distress-based condition indices are known as "leading indicators", which enable agencies to apply preventive measures when the first signs of distress appear (Tan 2015). On the other hand, DOTs need to be sensitive to the opinions of the motorist. Users probably will not be able to judge a pavement's structural condition, but they can and will make evaluations based on smoothness. Thus, both kinds of evaluation methods are important.

Tables 7.1 and 7.2 summarize the matching of treatments to distress types for asphalt- and concrete-surfaced pavements, respectively. The Peshkin et al. windows-of-opportunity (best time to apply the treatment) are in terms of PCI/PCR. MoDOT has recently adopted a 10-point PASER-like rating system. A conversion table between PCI and PASER is presented later. The Pavement Condition Index (PCI)-type system, developed by the U.S. Army Corps of Engineers and adopted by ASTM, is widely used. It is based on a deduct system which considers the severity and extent of measured types of distress. The Pavement Condition Rating (PCR) is similar in nature to the PCI.

To use the tables, distress type, extent, and severity descriptions (High, Medium, and Low) are necessary and can be found in the "*Distress Identification Manual for the Long Term Pavement Performance Program*" (Miller and Bellinger 2003).

Table 7.1 – Matching treatment type to distress type for asphalt-surfaced pavements (Peshkin et al. 2011b)

Treatment	PCI/ PCR	Ravel/ Weather			Bleed	Polish	Cracking L = Low M = Medium H = High														
							Fatigue[b]/ Long WP[c]/ Slippage			Block			Trans Thermal[c]			Joint Reflect			Long/ Edge[d]		
		L	M	H			L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Crack filling	75-90									x									X		
Crack sealing	80-95									X			X	X		X	X				
Profile milling	80-90		x	x	x																
Slurry sealing	70-85	x	x	x		x	x			x	x		x			x			x		
Micro-surfacing	70-85	x	x	x		x	x			x	x		x	x		x			x		
Chip seal, single	70-85	x	x	x		x	x			x	x		x	x		x	x		x	x	
Chip seal, double	70-85		x	x		x	x			x	x	x	x	x	x			x	x	x	x
UBAWS	65-85	x	x	x		x	x			x	x		x	x		x	x		x	x	
Thin overlay	60-80	x	x	x		x	x	x		x	x	x	x	x	x	x	x	x	x	x	x
Mill & overlay	60-75		x	x			x	x			x	x	x	x	x	x	x	x		x	x
Hot in-place recycling[a]	70-85		x	x			x	x		x	x			x	x		x	x	x	x	
Cold in-place recycling	60-75						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ultrathin White-topping	60-80					x		x	x		x	x		x	x		x	x		x	x
Fog seal							x														
Scrub seal							x														

[a] Surface recycle/HMA overlay

[b] Fatigue(alligator) cracking: L= < ¼" width or <10% area; M= ¼-½"or 10-20%; H = ½" or 20-30%

[c] Longitudinal Wheel Path and Transverse cracking: L= < ¼" width; M= ¼-½"; H = ½" width

[d] Edge cracking: L = no material loss; M = 0-10% loss; H = >10% loss

[e] "X" = highly or generally recommended

Table 7.1 – Matching treatment type to distress type for asphalt-surfaced pavements (Peshkin et al. 2011b), cont'd.

Treatment	PCI/ PCR	Ride	Friction	Noise	Deformation L = Low M = Medium H = High											
					Wear/ Stable* Rutting			Corrug/ Shove			Bumps/ Sags			Patches		
					L	M	H	L	M	H	L	M	H	L	M	H
Crack filling	75-90															
Crack sealing	80-95															
Profile milling	80-90	x			x	x					x	x		x	x	
Slurry sealing	70-85		x	x										x		
Micro-surfacing	70-85		x	x	x									x		
Chip seal, Single	70-85		x		x									x	x	
Chip seal, double	70-85	x	x		x	x		x			x			x	x	x
UBAWS	65-85	x	x	x	x			x			x			x	x	
Thin overlay	60-80	x	x	x	x	x	x	x	x		x	x		x	x	x
Mill & overlay	60-75	x	x		x	x	x	x	x	x	x	x	x	x	x	x
Hot in-place recycling[a]	70-85	x	x		x	x	x	x	x		x	x		x	x	
Cold in-place recycling	60-75	x	x		x	x	x	x	x	x		x	x		x	x
Ultrathin White-topping	60-80	x				x	x		x	x					x	x
Fog seal																
Scrub seal																

***Stable rutting is related to densification, not plastic deformation**

Table 7.2 – Matching treatment type to distress type for concrete-surfaced pavements (Peshkin et al. 2011b)

Treatment	PCI/ PCR	D-Cracking			Surface Distress		Joint Distress L=Low M=Medium H=High						Cracking Distress L =Low M= Medium H = High						Map Crack/ Scale
		L = Low M = Med H = High			Polish	Pop-outs	Joint Seal Damage			Joint Spall			Corner Cracks			Long/ Trans Cracks			
		L	M	H			L	M	H	L	M	H	L	M	H	L	M	H	
Joint resealing	75-90							x	x										
Crack sealing	70-90												x	x		x	x		
Diamond grinding	70-90				x														X
Diamond grooving	70-90																		
UBAWS	70-90	x			x												X		X
Thin overlay	70-90	x			x												x		x
Partial depth patching	65-85					x				x	x	x						x	
Full-depth patching	65-85		x	x					x				x	x	x				
Dowel-bar retrofit	65-85																		

Table 7.2 – Matching treatment type to distress type for concrete-surfaced pavements (Peshkin et al. 2011b), cont'd.

Treatment	PCI/ PCR	Ride	Friction	Noise	Deformation L=Low M=Medium H=High					
					Faulting			Patches		
					L	M	H	L	M	H
Joint resealing	75-90									
Crack sealing	70-90									
Diamond grinding	70-90	x	x	x	x	x	x	x	x	x
Diamond grooving	70-90		x	x						
UBAWS	70-90	x	x	x	x			x	x	x
Thin overlay	70-90	x	x	x	x			x	x	x
Part.depth patching	65-85								x	
Full-depth patching	65-85	x					x		x	x
Dowel-bar retrofit	65-85					x	x			

Tables 7.3 and 7.4 are shown as an aid in defining various conditions in the MoDOT highway system. The source is the MoDOT "*Maintenance Quality Assurance Performance Indicators Inspectors Rating Manual*" (MoDOT 2010b). Although the ratings are in terms of Pass/Fail, it appears that "Pass" would be similar to "Low", and "Fail" would correspond to "Moderate" and "High" in other rating schemes.

Table 7.3 – MoDOT performance indicators for asphalt (MoDOT 2010b)

Characteristic	Performance Indicator (0.1 Mile Segment)
Potholes If Rated: P & F only	A pothole is defined as any defect greater than or equal to 1.0 in. in depth and 72 sq. in. in area. Allowable number: Major Highways = 0, Minor Highways = 1.
Cracking If Rated: P & F only	100% of the Major Highways and 90% of the Minor Highways shall be free of unsealed cracks greater than or equal to 0.25 in. No areas of alligator / map cracking greater than 25 sq. ft. on the Major Highways or 75 sq. ft. on the Minor Highways shall exist.
Raveling/Stripping If Rated: P & F only	95% of the pavement surface shall be free of evidence of dislodged aggregate particles greater than 1/4 in. for Major Highways and 90% for Minor Highways.
Edge Breakup If Rated: P & F only	100% of the total roadway edge, within the outermost 4 in., shall be free of raveling or broken pavement and 95% for Minor Highways. (50 ft. allowed)
Bleeding/Flushing If Rated: P & F only	The sum of the affected areas shall not be greater than 25 sq. ft. on the Major Highways and not greater than 75 sq. ft. on the Minor Highways.
Shoving If Rated: P & F only	No area on the Major Highways shall exhibit the appearance of shoving. 90% of the pavement surface on Minor Highways shall not exhibit the appearance of shoving.
Rutting If Rated: P & F only	90% of the pavement surface shall be free of ruts greater than 0.25 in. in depth and no rut greater than 0.5 in. in depth and over 4 ft. in length shall exist.
Depressions/Bumps If Rated: P & F only	No vertical deviation in the pavement profile with length equal or less than 4 feet shall be greater than 1/4 in. on Major Highways and 5/8 in. on Minor Highways This does not apply to depressions less than 1 in. in width in cracks.
Patching If Rated: P, F & N/A	Majors routes: Rotomilled patches that are equal or greater than 72 sq. in. in area and greater than 0.25 in. higher or lower than the adjacent pavement surface do not meet standards and will be classified as a substandard patch. Minor routes: Surface patches greater than 5/8in. higher than the adjacent pavement surface do not meet standards and will be classified as a substandard patch. Allowable number of substandard patches: Major Highways = 0, Minor Highways = 2. For aesthetic reasons, no more than a total of 5 patches per lane shall exist on any system.

Table 7.4 – MoDOT performance indicators for concrete (MoDOT 2010b)

Characteristic	Performance Indicator (0.1 Mile Segment)
Potholes If Rated: P & F only	A pothole is defined as any defect greater than or equal to 1.0 in. in depth and 72 sq. in. in area. Allowable number: Major Highways = 0, Minor Highways = 1.
Spalls/Popouts If Rated: P & F only	95% of the roadway surface shall be free of spalls/popouts greater than 0.5 in. in depth and 2 in. in diameter. Less than 10% of cracks and joints have spalled to a surface width of 2 in. and a depth of 0.5 in.
Cracking If Rated: P & F only	100% of the Major Highways and 90% of the Minor Highways shall be free of unsealed cracks greater than or equal to 0.25 in. in width. No areas of alligator / map cracking greater than 25 sq. ft. on the Major Highways or 75 sq. ft. on the Minor Highways shall exist.
Joints If Rated: P & F only	90% of the length of all joints shall be sealed and functioning as intended. No evidence of D-cracking shall exist.
Depressions/Bumps If Rated: P & F only	No vertical deviation in the pavement profile shall be greater than 1/4 in. on Major Highways and 5/8 in. on Minor Highways.. This does not apply to depressions in cracks less than 1 in. in width or faults.
Pumping If Rated: P & F only	100% of the pavement slabs shall show no evidence of pumping.
Faulting If Rated: P & F only	100% of the joints and cracks shall not exhibit a difference in the elevation of the adjacent sections of pavement greater than or equal to 0.25 in.
Patching If Rated: P, F & N/A	Rotomilled patches that are equal or greater than 72 sq. in. in area and greater than 0.25 in. higher or lower than the adjacent pavement surface do not meet standards and will be classified as a substandard patch. Minor routes only: Surface patches greater than 5/8in. higher than the adjacent pavement surface do not meet standards and will be classified as a substandard patch. Allowable number of substandard patches: Major Highways = 0, Minor Highways = 2. For aesthetic reasons, no more than a total of 5 patches per lane shall exist on any system.

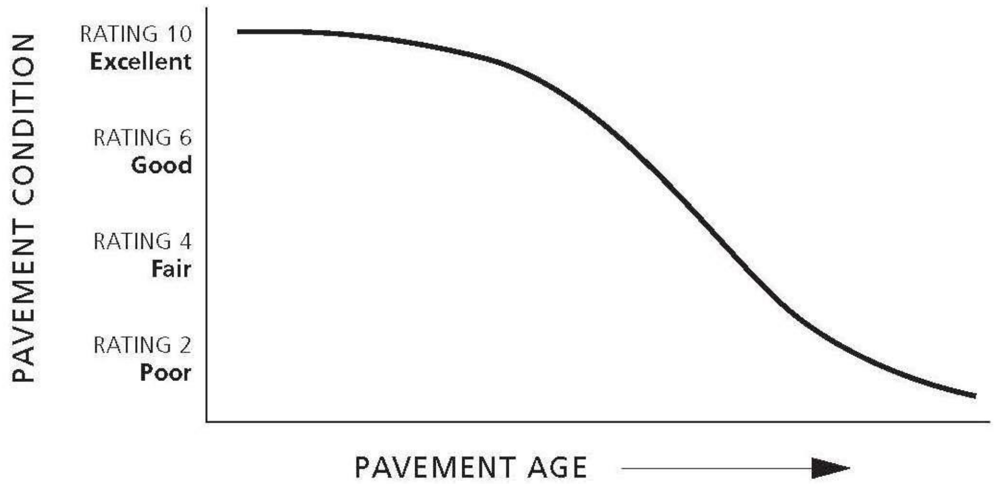
Additionally, the pavement condition leads to the target goals of the treatment such as: 1) improve smoothness (only), 2) improve friction, 3) reduce noise, 4) slow aging, or 5) improve surface drainage (splash/spray, cross slope). Improving “structural condition/ enhance structural capacity” actually falls under rehabilitation.

The effect of initial overall condition impacts the service life of the treatment. An increase in life extension of up to 4-5 years has been seen when starting at a good condition compared to a fair condition.

Figs. 7.1 and 7.2 show the PASER rating system and action items for asphalt, and Figs. 7.3 and 7.4 are the concrete counterparts to Figs. 7.1 and 7.2.

Surface rating	*Visible distress**	*General condition/ treatment measures*
10 Excellent	None.	New construction.
9 Excellent	None.	Recent overlay. Like new.
8 Very Good	No longitudinal cracks except reflection of paving joints. Occasional transverse cracks, widely spaced (40′ or greater). All cracks sealed or tight (open less than 1/4″).	Recent sealcoat or new cold mix. Little or no maintenance required.
7 Good	Very slight or no raveling, surface shows some traffic wear. Longitudinal cracks (open 1/4″) due to reflection or paving joints. Transverse cracks (open 1/4″) spaced 10′ or more apart, little or slight crack raveling. No patching or very few patches in excellent condition.	First signs of aging. Maintain with routine crack filling.
6 Good	Slight raveling (loss of fines) and traffic wear. Longitudinal cracks (open 1/4″–1/2″), some spaced less than 10′. First sign of block cracking. Sight to moderate flushing or polishing. Occasional patching in good condition.	Shows signs of aging. Sound structural condition. Could extend life with sealcoat.
5 Fair	Moderate to severe raveling (loss of fine and coarse aggregate). Longitudinal and transverse cracks (open 1/2″) show first signs of slight raveling and secondary cracks. First signs of longitudinal cracks near pavement edge. Block cracking up to 50% of surface. Extensive to severe flushing or polishing. Some patching or edge wedging in good condition.	Surface aging. Sound structural condition. Needs sealcoat or thin non-structural overlay (less than 2″)
4 Fair	Severe surface raveling. Multiple longitudinal and transverse cracking with slight raveling. Longitudinal cracking in wheel path. Block cracking (over 50% of surface). Patching in fair condition. Slight rutting or distortions (1/2″ deep or less).	Significant aging and first signs of need for strengthening. Would benefit from a structural overlay (2″ or more).
3 Poor	Closely spaced longitudinal and transverse cracks often showing raveling and crack erosion. Severe block cracking. Some alligator cracking (less than 25% of surface). Patches in fair to poor condition. Moderate rutting or distortion (1″ or 2″ deep). Occasional potholes.	Needs patching and repair prior to major overlay. Milling and removal of deterioration extends the life of overlay.
2 Very Poor	Alligator cracking (over 25% of surface). Severe distortions (over 2″ deep) Extensive patching in poor condition. Potholes.	Severe deterioration. Needs reconstruction with extensive base repair. Pulverization of old pavement is effective.
1 Failed	Severe distress with extensive loss of surface integrity.	Failed. Needs total reconstruction.

Fig. 7.1 - PASER asphalt rating system (Walker et al. 2002a).



In addition to indicating the surface condition of a road, a given rating also includes a recommendation for needed maintenance or repair. This feature of the rating system facilitates its use and enhances its value as a tool in ongoing road maintenance.

RATINGS ARE RELATED TO NEEDED MAINTENANCE OR REPAIR

Rating 9 & 10	No maintenance required
Rating 8	Little or no maintenance
Rating 7	Routine maintenance, cracksealing and minor patching
Rating 5 & 6	Preservative treatments (sealcoating)
Rating 3 & 4	Structural improvement and leveling (overlay or recycling)
Rating 1 & 2	Reconstruction

Fig. 7.2 – PASER ratings related to actions for asphalt (Walker et al. 2002a).

Surface rating	Visible distress*	General condition/ treatment measures
10 Excellent	None.	New pavement. No maintenance required.
9 Excellent	Traffic wear in wheelpath. Slight map cracking or pop-outs.	Recent concrete overlay or joint rehabilitation. Like new condition. No maintenance required.
8 Very Good	Pop-outs, map cracking, or minor surface defects. Slight surface scaling. Partial loss of joint sealant. Isolated meander cracks, tight or well sealed. Isolated cracks at manholes, tight or well sealed.	More surface wear or slight defects. Little or no maintenance required.
7 Good	More extensive surface scaling. Some open joints. Isolated transverse or longitudinal cracks, tight or well sealed. Some manhole displacement and cracking. First utility patch, in good condition. First noticeable settlement or heave area.	First sign of transverse cracks (all tight); first utility patch. More extensive surface scaling. Seal open joints and other routine maintenance.
6 Good	Moderate scaling in several locations. A few isolated surface spalls. Shallow reinforcement causing cracks. Several corner cracks, tight or well sealed. Open (1/4" wide) longitudinal or transverse joints and more frequent transverse cracks (some open 1/4").	First signs of shallow reinforcement or corner cracking. Needs general joint and crack sealing. Scaled areas could be overlaid.
5 Fair	Moderate to severe polishing or scaling over 25% of the surface. High reinforcing steel causing surface spalling. Some joints and cracks have begun spalling. First signs of joint or crack faulting (1/4"). Multiple corner cracks with broken pieces. Moderate settlement or frost heave areas. Patching showing distress.	First signs of joint or crack spalling or faulting. Grind to repair surface defects. Some partial depth patching or joint repairs needed.
4 Fair	Severe polishing, scaling, map cracking, or spalling over 50% of the area. Joints and cracks show moderate to severe spalling. Pumping and faulting of joints (1/2") with fair ride. Several slabs have multiple transverse or meander cracks with moderate spalling. Spalled area broken into several pieces. Corner cracks with missing pieces or patches. Pavement blowups.	Needs some full depth repairs, grinding, and/or asphalt overlay to correct surface defects.
3 Poor	Most joints and cracks are open, with multiple parallel cracks, severe spalling, or faulting. D-cracking is evident. Severe faulting (1") giving poor ride. Extensive patching in fair to poor condition. Many transverse and meander cracks, open and severely spalled.	Needs extensive full depth patching plus some full slab replacement.
2 Very Poor	Extensive slab cracking, severely spalled and patched. Joints failed. Patching in very poor condition. Severe and extensive settlements or frost heaves.	Recycle and/or rebuild pavement.
1 Failed	Restricted speed. Extensive potholes. Almost total loss of pavement integrity.	Total reconstruction.

Fig. 7.3 - PASER concrete rating system (Walker et al. 2002b).

RATINGS ARE RELATED TO NEEDED MAINTENANCE OR REPAIR

Rating 9 & 10	New pavement or recent concrete rehabilitation. No maintenance required.
Rating 7 & 8	First signs of wear, scaling, or cracking. Needs routine maintenance.
Rating 5 & 6	First signs of corner cracks, faulting, and joint or crack spalling. Requires surface repairs, sealing or partial depth patching.
Rating 3 & 4	Moderate to severe faulting, multiple slab cracking, and joint failure. Requires extensive slab or joint rehabilitation.
Rating 1 & 2	Pavement failure requiring complete reconstruction.

Fig. 7.4 – PASER ratings related to actions for concrete (Walker et al. 2002b).

Table 7.5 shows the PCI/PASER equivalencies used by the Kent County Road Commission in Michigan (KCRC), which were attributed to the creator of the PASER system, the University of Wisconsin (KCRC 2002). Action items linked to the ratings are included. The ratings/actions do not exactly match Peshkin et al. recommendations in Tables 7.1 and 7.2. Also shown are the ratings as planned by MoDOT in its Pavement Maintenance Direction report (MoDOT 2010a).

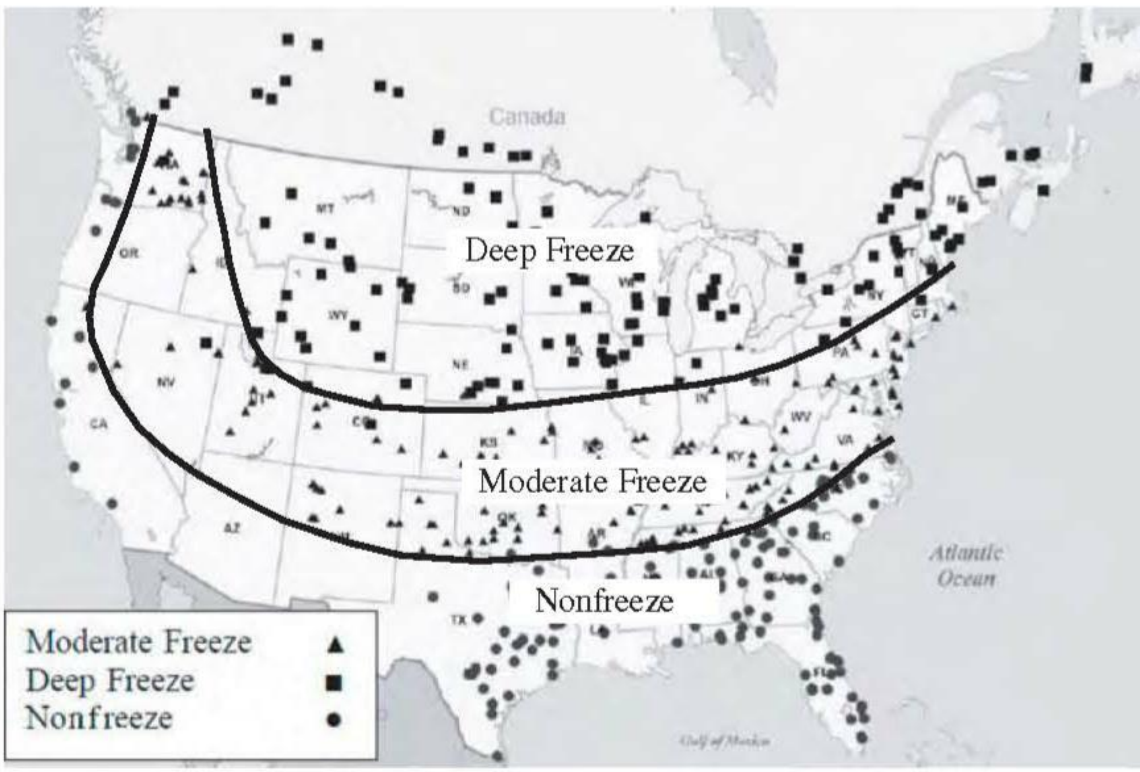
Table 7.5 – PCI-PASER equivalencies

<table>
<tr><th colspan="2">KCRC</th><th colspan="2" rowspan="2">KCRC/PASER Manual</th><th colspan="3">MoDOT Direction</th></tr>
<tr><th>PCI</th><th>PASER</th><th>Major</th><th>Minor >400 AADT</th><th>Miner <400 AADT</th></tr>
<tr><td>95-100</td><td>10</td><td>Excellent</td><td>No maintenance</td><td rowspan="4">Good</td><td rowspan="6">Good</td><td rowspan="8">Good</td></tr>
<tr><td>86-94</td><td>9</td><td>Excellent</td><td>No maintenance</td></tr>
<tr><td>80-85</td><td>8</td><td>Very Good</td><td>Little or no maintenance</td></tr>
<tr><td>71-79</td><td>7</td><td>Good</td><td>Routine maintenance</td></tr>
<tr><td>65-70</td><td>6</td><td>Good</td><td>Preservative Treatment</td><td rowspan="6">Not Good</td></tr>
<tr><td>56-64</td><td>5</td><td>Fair</td><td>Preservative Treatment</td></tr>
<tr><td>50-55</td><td>4</td><td>Fair</td><td>Structural improvement and leveling</td><td rowspan="4">Not Good</td></tr>
<tr><td>41-49</td><td>3</td><td>Poor</td><td>Structural improvement and leveling</td></tr>
<tr><td>26-40</td><td>2</td><td>Very Poor</td><td>Reconstruction</td><td rowspan="2">Not Good</td></tr>
<tr><td>0-25</td><td>1</td><td>Failed</td><td>Reconstruction</td></tr>
</table>

Barrette (2011) attempted to correlate PCI to PASER, without much success. This was attributed to the difference in weighting of various distresses between the two systems, as well as the different distress types considered. PASER considers 12 distresses, while PCI has 19. The KCRC report showed that the two systems did not produce similar ratings at the high and low ends of the scale: PASER rating is less critical on severely deteriorated roads and more critical on excellent roads. Thus fewer sections were rated as No Maintenance and Reconstruction with PASER than with PCI, whereas PASER placed more sections in the middle categories than PCI. One example of the inability to match systems is the impact of a new treatment. A new chip seal would be rated as 100 in the PCI system, but no higher than 8 in the PASER system.

7.1.3 Climate and Weather

Climate and weather affect the choice of treatment type in two ways: 1) treatment performance and 2) construction timing. Treatments vary in their sensitivity to climate and weather: some are affected minimally (diamond grinding) while most others are affected significantly; some can be quite sensitive, such as those involving emulsions. Thin overlays can be susceptible to cold temperature cracking. Some thin surfacing types are more susceptible to certain types of snow-plowing (techniques and plow blades), and deicers affect crack sealing quality. Fig. 7.5 shows the U.S. divided into three climate zones. Missouri is mostly in the "Moderate Freeze" zone. However, the northern counties fall in the "Deep Freeze" zone. Thus, choices of treatment types may vary according to location in the state, e.g. slurry seals and crack sealing suffer more in freezing climates (although interestingly, both Iowa and Illinois DOTs list slurry seals in their surface treatments specifications). Overall studies indicate that there is a several-year reduction in life for treatments in freezing environments.



Source: Adapted from Jackson and Puccinelli 2006.

Fig. 7.5 – Climate zones in the US (Peshkin et al. 2011a).

In regard to construction timing, expected weather during construction affects the type of treatment; typically start/stop dates are used for restricting construction activities for specific treatments. Climate impacts curing time and thus opening to traffic. Chip seals can be sensitive to the weather some weeks after construction.

7.1.4 Work Zone Duration Restrictions

The time available to apply a treatment relates to the traffic volume and speed, driving difficulty, facility setting, and so forth. Some traffic-related situations are more sensitive than others to down-time of a facility. Almost all of the preservation techniques discussed in this report can satisfy the tightest restrictions of single work shift, with the exceptions of ultra-thin whitetopping, partial- and full-depth repairs, and dowel bar retrofitting.

7.1.5 Roadway Geometrics

The presence of features such as significant horizontal/vertical curves, intersections/ interchanges, overhead bridges/sign structures, paved shoulders, and curb-and-gutter may be problematic to the construction of certain types of treatments.

7.1.6 Experience with Treatment

Availability of an experienced workforce and DOT familiarity with the treatment may dictate whether a certain treatment is used or not. Wu et al. (2010) suggest rating the construction experience of the workforce (contractor or DOT maintenance) and the DOT's experience with a particular type of treatment as follows: High = treatment is used routinely; Medium = treatment is sometimes used or has been used for 5 years or less; Low = treatment is not regularly used or is used in pilot projects.

7.1.7 Availability of Good Quality Materials

Some areas of the state are known for a lack of quality of the available aggregates, or of certain desired aggregate types. For instance, hard aggregate such as trap rock are preferable over softer limestones for chip sealing. A decision needs to be made as to which is preferable: higher shipping costs or shorter service lives.

7.1.8 Availability of Specialized Equipment and Materials

Certain treatments require specialized equipment and/or materials, such as micro-surfacing, onyx seals, in-place recycling, UBAWS, and diamond grinding. This fact may eliminate one or more of these treatments in a given locale or design situation.

7.1.9 Environmental Considerations

More emphasis may be placed on certain construction activities in certain locations (e.g. urban areas) that are sensitive to environmental concerns or agenda. Techniques that involve recycling and sustainable concepts may be desirable.

7.1.10 Expected Performance

Expected performance needs to be determined in order to perform cost effectiveness calculations and to program treatments. There can be a difference between: 1) how long a treatment lasts before it reaches a predetermined action threshold (e.g. IRI = 170 in./mile), 2) how long the treatment extends the service life of the pavement, and 3) how long the interval is between treatments. The treatment interval may be shorter or longer than the other two definitions of life, e.g., the target threshold terminal IRI may have been reached but the treatment was delayed for a while. Most reports define "Treatment Life" as the interval in time that it takes for the treated condition to reach the condition level that it started out at, e.g. if the existing IRI_t was 150 in./mile, then was overlaid, then over time deteriorated again to 150 in./mile, the Treatment Life (TL) is the number of years that it took the treated pavement to reach the 150 in./mile mark. "Service Life Extension" (SLE) is the difference between the

Remaining Service Life (before treatment) [RSL_{BT}] and the Remaining Service Life (after treatment) [RSL_{AT}] (Dawson et al. 2012). In other words, the SLE is the net benefit provided by the treatment. Using an example of IRI_t of 150 in./mile, all four definitions are shown in Fig. 7.6. If the two curves are approximately parallel, the TL will be close in magnitude to the SLE. Both types of definitions of performance lives are reported in the literature.

Presently, with MoDOT's 20-point Condition Index phased out and PASER ratings still in their infancy, only IRI is available for analysis, and hence RSL, SLE, and TL determinations are based on IRI only. In the future, when PASER models can be developed, the RSL, SLE, and TL time intervals will be able to be calculated for PASER lives as well as IRI lives. At that point, the shortest of the two intervals (IRI or PASER) will be the controlling interval (life).

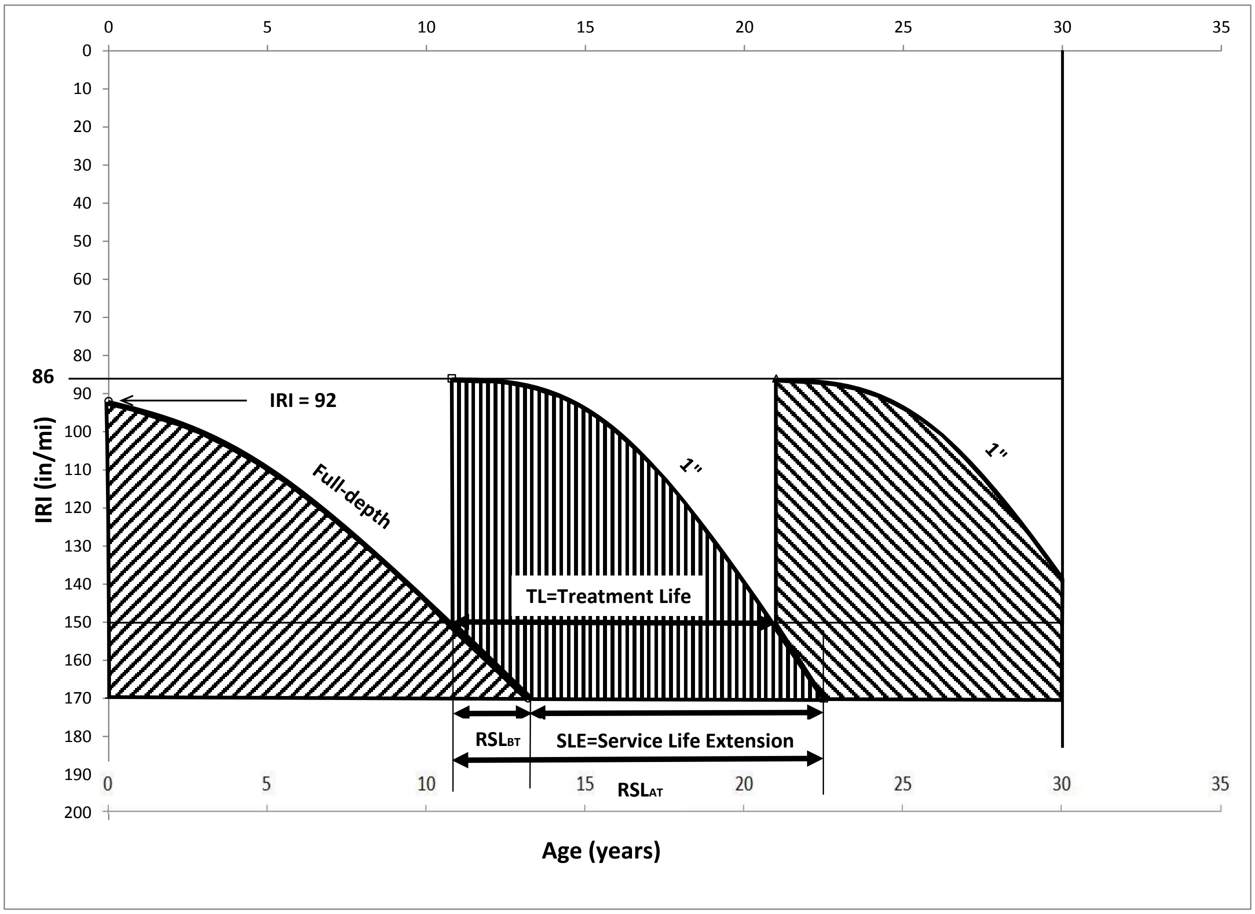


Fig. 7.6 – Treatment Life, Service Life Extension, Remaining Service Life (before treatment), and Remaining Service Life (after treatment).

To give an idea of how RSLs play into treatment selection, Table 7.6 is a Michigan DOT treatment selection trigger table based in part on RSL. For more details, Zimmerman et al. (2011) should be reviewed.

Table 7.6 – Michigan DOT RSL levels for treatment and restoration

RSL Range (yrs)	Allowable Treatment
Flexible	
≥ 10	Single course micro-surface; crack treatments
≥ 6	Single course chip seals
≥ 5	Double course chip seals; multiple course micro-surface
≥ 3	Thin overlays; mill and fill
Concrete	
≥ 12	Diamond grinding
≥ 10	Crack sealing; clean & seal joint; dowel bar retrofit
≥ 3	Concrete pavement restoration

Table 7.7 presents expected performance of various *preservation* treatments, and Table 7.8 presents expected performance of various *rehabilitation* treatments. Performance is a function of pavement condition, traffic volume/axle load distribution, climate, construction quality, and environment of the pavement, i.e. drainage quality. To account for influential factors of existing pavement condition, climate, and construction quality risk, it is recommended that values be chosen near the lower limits for "fair" pavement conditions, more severe climates, and higher construction quality risk, and vice-versa for more favorable situations. Treatment lives reported in the MoDOT Pavement Maintenance Direction (2010a) are discussed in section 7.3.3.

In regard to chip seals, double chip seals (two applications of chips and binder) offer several benefits over single chip seals. Table 7.1 shows that for those applications appropriate for chip seals, double chip seals extend into the High severity conditions where single seals are not recommended, and are useful for improving smoothness, friction, medium severity stable rutting and other types of deformations, and for improving high severity patching. The Asphalt Institute MS-19 notes that double chip seals will give about three times the service life of a single chip seal for about 1.5 times the construction cost. More conservatively, Table 7.7 shows an extension of 3 to 4 years of double seals over single seals.

Table 7.7 – Expected performance of preservation treatments (Wu et al. 2010; Peshkin et al. 2011b; ILDOT 2009)

Treatment	Distress Triggers	Treatment Life (yrs) [Peshkin et al.]	Performance Period (yrs) [ILDOT]	Pavement Life Extension (yrs)	
				[Wu et al.]	[Peshkin et al.]
Asphalt-Surfaced					
Crack filling		2-4	2-4		NA
Crack sealing	Cracking (various)	3-8	2-8	0-4	2-5
Slurry seal	Ride, cracking (various)	3-5*	3-6	4-7	4-5
Micro-surfacing:	Cracking (various), shallow rutting		4-7		
Single course		3-6**		3-8	3-5
Double course		4-7			4-6
Chip seal:	Cracking (various), raveling	[redacted]			
Single course		3-7	4-6	3-8	5-6
Double course		5-10***	5-7		8-10
Triple course			6-8		
UBAWS		7-12	7-12		NA
Thin overlay	Ride, cracking (various), rutting, raveling	5-12****	7-10	3-23	NA
Mill & thin overlay	Ride, cracking (various), rutting	5-12	7-10	4-20	NA
Hot in-place recycling, thin overlay	Cracking (various), rutting	6-10	6-15	3-8	NA
Cold in-place recycling, thin overlay	Cracking (various), rutting	6-15	5-13	4-17	NA
Profile milling		2-5	0		NA
Fog sealing	Cracking patching		1-3	4-5	
Sand seal			3-4		
Cape seal			4-7		
¾" overlay + chip seal			5-7		
Whitetopping	Ride, cracking (various)			3-17	

Concrete-Surfaced					
Joint resealing	Ride; open joints	2-8	4-8 (Hot pour asphalt) 8 (Silicone)	4	5-6
Crack sealing		4-7	4-8		NA
Diamond grinding	Ride, faulting	8-15	8-15	4-17	NA
Diamond grooving		10-15	0		NA
Partial depth patching	Cracked panels, joint spalling	5-15	5-15	1-7	NA
Full depth patching	Ride, cracked panels	5-15	10-15	3-14	NA
Dowel bar retrofitting	Ride, cracked panels with some faulting and transverse joint spalling	10-15	10-15	2-16	NA
UBAWS		6-10	7-12		NA
Thin HMA overlay	Ride, faulting, cracked panels	6-10		1-20	NA

*4.8, **7.4, *** 7.3, **** 8.4 Watson and Heitzman (2014)

Table 7.8 – Expected performance of rehabilitation treatments (Wu et al. 2010)

Treatment	Distress Triggers	Treatment Life (yrs)	Pavement Life Extension (yrs)
Asphalt-Surfaced			
Full depth reclamation	Ride, cracking (various), severe rutting		10-20
Mill & fill structural overlay	Ride, cracking (various)		6-17
Concrete-Surfaced			
Crack & seat/rubblize and HMA overlay	Ride, faulting, cracked panels, spalled joints		10-15
Unbonded overlay	Ride, cracked panels		15-31

To estimate ranges of service lives of 1-in. HMA overlays in a rational manner, nine conditions were modeled in AASHTOWare: three for a low IRI_o (55 in./mile), three for a moderate IRI_o (86), and three for a fair IRI_o (100 in./mile). Within each of the three IRI_o sets, the "Infrastructure Quality Rating (IQR)" was varied among Good, Fair, and Poor. A "Good" IQR was characterized as a good asphalt mix (good volumetrics and gradation), an excellent existing pavement, a good subgrade (A-1-a), a less severe climate (least FT cycles in Missouri), and a 5 in. thick existing asphalt pavement. A "Fair" IQR was characterized as a good asphalt mix (good volumetrics and gradation), a fair existing pavement, a fair subgrade (A-6), a moderate climate (median number of FT cycles in Missouri), and a 4 in. thick existing asphalt pavement. A "Poor" IQR was characterized as a poor asphalt mix (poor volumetrics and gradation), a very poor existing pavement, a poor subgrade (A-7-6 with high Atterberg limits and P200), a poor climate (maximum number of FT cycles in Missouri), and a 2 in. thick existing asphalt pavement. The range of predicted lives was calculated, and the range of lives for each IRI_o was determined. These ranges were 3.0 years, 1.5 years, and 0.75 year for each category of IRI_o. The application of these values would be applied to the average lives of 1-in. surface leveling overlays: say for an ideal predicted life of 17.5 years, the range would be 14.5 to 20.5. For a moderate prediction of 12.5 years, the range would be 11 to 14 years. For a poorer prediction of 6 years, the range would be 5 to 7 years.

7.1.11 Availability of Funding/Cost

Availability of funding for different treatment times of intervention is part of the agency's programming, and may affect the choice of treatment. Treatment costs depend on size of project, location of project, severity and quantity of distresses, quality of the treatment's construction materials, type and amount of surface preparation work, and level of traffic control. In regard to distresses, allowing a roadway to deteriorate costs more than maintaining the roads in acceptable condition. Table 7.9 lists unit costs from two national surveys of preservation treatments, exclusive of traffic control and surface preparation costs. Missouri costs are discussed in section 7.3.4.

Table 7.9 - Estimated costs for preservation treatments (Peshkin et al. 2011b)

Treatment	Unit Cost ($)
Asphalt-Surfaced	
Crack filling	0.10-1.20/ft
Crack sealing	0.75-1.50/ft
Slurry sealing	0.75-1.00/yd^2
Micro-surfacing (single-course)	*1.50-3.00/ yd^2
Chip seal (single course)	***1.50-2.00/ yd^2
UBAWS	4.00-6.00/ yd^2
Thin overlay	**4.00-6.00/ yd^2
Mill & thin overlay	5.00-10.00/ yd^2
Hot in-place recycling (excluding overlay)	2.00-7.00/ yd^2
Cold in-place recycling (excluding overlay)	1.25-3.00/ yd^2

Profile milling	0.35-0.75/ yd^2
PCC-Surfaced	
Joint resealing	1.00-2.50/ yd^2
Crack sealing	0.75-2.00/ yd^2
Diamond grinding	1.75-5.50/ yd^2
Diamond grooving	1.25-3.00/ yd^2
Partial depth patching	75.00-150.00/ yd^2 (patched area; equivalent 2.25-4.50/ yd^2 based on 3% surface area patched)
Full depth patching	75.00-150.00/ yd^2 (patched area; equivalent 2.25-4.50/ yd^2 based on 3% surface area patched)
Dowel bar retrofitting	25.00-35.00/bar (equivalent 3.75-5.25/ yd^2, based on 6 bars per 12-ft crack/joint and crack/joint retrofits every 30 ft)
UBAWS	4.00-6.00/ yd^2
Thin overlay	3.00-6.00/ yd^2

* $2.19, ** $2.07 Watson and Heitzman (2014)
*** $1.78 MoDOT Tracker 2010 season, contracted

7.2 Other Agency Experience

7.2.1 National Synthesis Reports

Wu et al. (2010) conducted a survey of 256 projects from six states covering 20 specific treatment types. It was noted that pavement condition data (ride, distress) were collected using different strategies per state, making comparisons across states difficult. The problems that other state DOTs had with extracting data from their own systems fell into three general issues: 1) all the data exists, but could not be linked effectively and/or efficiently, 2) the data did not exist, and 3) the data had not been collected for a long enough period of time. It was interesting to note that all three of these issues were encountered during the MoDOT Preservation study. Thus, MoDOT is not alone in where it stands in regard to development of a pavement management system. Additionally, Wu et al. noted that the process for collecting and analyzing pavement performance data changes over time, which makes it difficult to perform long-term studies of treatment performance. Again, this was encountered in the MoDOT study. A specific example of a change is the abandonment of the 20-point Condition Index rating system in favor of the PASER-like system.

None of the states in the survey used a formalized method to determine the extended service life for their treatments. In terms of construction history and cost data, state DOTs either 1) do not have the data, or 2) the data is stored in systems “which they cannot access, do not understand, or do not have the time to manipulate the data”. An example would be that the last treatment year is missing. Another example is the possibility of separation of pavement and non-pavement related costs; this is possible to do but the states are unwilling to spend the time and effort to do so. Improvements to DOT systems to collect and link traffic, condition, construction, and maintenance history were needed.

Another issue that clouds the strategies behind preservation decisions is that pavements are rehabilitated for a number of reasons other than condition, including political, budgetary, and aesthetics. So, life extension is not based solely on condition, making cause-and-effect difficult to nail down.

Wu et al. recommended that DOTs should develop and implement an *integrated* management system where the system would be able to link treatment type, treatment date, treatment location, cost, previous construction history, and performance information over a long period of time. Identification of the reasoning behind the use of a particular treatment and inclusion in the decision-making process should also be a part of the system.

Other national synthesis reports are discussed elsewhere in this report: Zimmerman et al. (2011) in Section 1.2; Peshkin et al. (2011b) in Sections 1.2, 7.1, 7.2, 7.3, 7.5; Scofield et al. (2011) in Subitem 7.2.2.3; Pierce and Kebede (2015) in Subitem 7.3.3.1.f; and Watson and Heitzman (2014) in Item 7.4.2.

7.2.2 States Surrounding Missouri

Preservation Maintenance strategies of the DOTs in the four states geographically surrounding Missouri (Illinois, Arkansas, Kansas, and Iowa) were reviewed in an effort to supplement the research performed using MoDOT field data.

7.2.2.1 Illinois DOT

The Illinois DOT pavement preservation management manual (ILDOT 2009) was reviewed. The manual was comprehensive, transparent, easily accessed, easily understood, and used treatment type selection decision matrices for asphalt- and concrete-surfaced pavements. These matrices (tables) were similar to Tables 7.1 and 7.2 from Peshkin et al. Treatment types were based on individual distress types, severity, and extent, not on smoothness or overall condition index. Performance lives from the Illinois manual have been included in Table 7.7. Because of the close proximity of Illinois to Missouri, Illinois experience can be used to a certain degree because it is more applicable than nationally-derived data.

7.2.2.2 Arkansas DOT

The Arkansas DOT does not at present use formalized treatment selection trigger tables/decision trees. Discussions with DOT personnel indicated that there is an in-house research statement in existence that is aimed at evaluating certain types of seals.

7.2.2.3 Kansas DOT

The Kansas DOT has a comprehensive Pavement Management Information System in place, accessible at its website. However, it does not have some of the advantages mentioned in the ILDOT discussion. Pavements are surveyed in terms of IRI and various distresses, distress levels are determined, and an overall condition index is calculated. Along with another modifier that accounts for condition longevity based on the type of treatment that was last applied, the section combined score is fed into a network-level system to select the sections that will be treated. There are no trigger tables/decision trees as such "because the timing and type of treatment can vary based on conditions for other locations and available funds" (Scofield et al. 2011). The condition index is a combination of roughness level, a primary distress level, and a secondary distress level. For asphalt, the primary distress is transverse cracking and the secondary distress is rutting. For concrete, the primary is joint distress and the secondary is faulting. The various levels are:

- There are three IRI roughness levels (1, 2, 3): 1= <105, 2= 105-165, 3= >165 in./mile
- Three transverse crack levels (1, 2, 3): based on a combination of 4 codes which are based on severity and extent
- Three rutting levels (1, 2, 3): based on 4 codes which are calculated from severity codes relating to rutting of <0.25, 0.25-0.50, 0.51-1.0, >1.0 in.
- Three joint distress levels (1, 2, 3): based on a combination of 4 codes based on severity and extent
- Three faulting levels (1, 2, 3): based on 3 codes which are calculated from severity codes of <0.25, 0.25-0.5, >0.5 in.

Thus, an asphalt pavement may have a Distress State of 1-1-2, meaning low IRI, low transverse cracking, and medium rutting levels. A concrete pavement Distress State of 1-1-2 would be low IRI, low joint distress, and medium faulting.

The Distress States are combined with the Pavement Type and a resulting Performance Level is determined (Table 7.10):
1 = smooth and few defects-no corrective action required. May want to apply preventive maintenance to keep it good.
2 = some roughness and moderate surface defects; requires routine maintenance
3 = requires rehabilitative action

Table 7.10 – Kansas DOT performance levels

Distress State	**Performance Levels**			
	PCCP	**Composite**	**Full-Depth Bituminous**	**Partial-Depth Bituminous**
111, 112	1	1	1	1
113	1	1	1	2
121, 122	1	1	1	1
123	1	2	2	2
131,133	2	2	2	2
211	1	1	1	1
212	1	1	1	2
213	1	1	2	2
221	1	2	2	2
222	1	2	2	2
223	2	2	2	2
231-233	2	2	2	2
311	2	2	3	3
321-323	3	3	3	3
331-333	3	3	3	3

Treatments listed in the Kansas DOT construction manual are chip seals, crack sealing and re-sealing, cold in-place recycling, hot in-place recycling, UBAWS, and microsurfacing. HMA overlays were not called out specifically. There is no matching of treatments to condition indices generally available.

7.2.2.4 Iowa DOT

Iowa DOT uses decision trees to make network-level decisions about needs, but leaves the specific treatment (type, material, thickness) within a general treatment category. Trees and threshold triggers are as follows:

- HMA-surface *Crack Filling*: decision based on whether there was previous crack filling, years since last crack fill, and whether full-depth asphalt or composite pavement
- HMA-surface *Thin Surface Treatment*: decision based on ≤ ¾-in. rutting, friction number < 37, < 635 ft^2/mile alligator cracking, ≥ 5 years since last treatment, and IRI ≤ 140 in./mile.
- *Diamond grinding*: for PCC thickness ≥ 8 in., IRI ≥ 100 in./mile (Interstates) or 125 in./mile (non-interstates), or ≥ 3/8 in. faulting, or friction < 37
- *Minor Rehabilitation*: required change in Structural Number (SN) < 1.32 (3-in. overlay) alligator cracking < 1585 ft^2/mile, joint spalling ≤ 66 count/mile, friction < 37 or rutting ≥ 0.25 in. or IRI ≥ 100 or IRI ≥ 140 in./mile (non-interstate)
- *Major (structural) Rehabilitation* (3 to 4.5-in.): required change in Structural Number of 1.32 (3-in. overlay) (non-interstates) or 1.98 (4.5-in. overlay) (interstates), and soil k-value > 125 psi/in.
- *Major (structural) Rehabilitation* (> 4.5 in.): required increase in SN (1.32 and ≥ 1585 ft^2/mile alligator cracking and ≥ 66 count/mile joint spalling, or soil k-value > 125 psi/in.
- *Reconstruction:* SN need > 3.52 (8-in. overlay)

Treatments listed in the Iowa DOT specifications are chip seals, sand seals, slurry seals, fog seals, cold in-place recycling, hot in-place recycling, micro-surfacing, white topping, plus the above-mentioned HMA overlays, crack sealing, and diamond grinding. Diamond grinding and micro-surfacing are considered “Thin Surface Treatments”. There is no matching of treatments to condition indices specifically available.

7.2.2.5 Summary of Four State Pavement Treatment Selection Methodologies

Of the four states adjacent to Missouri, three had formalized pavement treatment selection methodology. Illinois DOT’s system was based on a matrix (table) matching specific distress type, severity, and extent to specific candidate treatments, with usually more than one candidate per pavement condition. There were 13 distresses for flexible/composite and 11 distresses for concrete pavements that were mapped to 20 specific treatments. Friction was included with both pavement types, but smoothness was only considered for concrete. Unfortunately, severity and extent evaluation was primarily subjective, with just rut depth and crack width tied to actual numerical values. Iowa DOT’s system involved decision trees with trigger thresholds based on functional classification and both smoothness and specific distresses. There were only two distresses each for asphalt and concrete, plus friction for both, mapped to a few specific treatments, with most mapped to general categories of treatments. Kansas DOT's system involved tables that considered three distress types plus smoothness, with severity and extent determined subjectively, leading to an overall condition index. However, condition was not mapped to treatments at the project level.

7.3 Approaches Involving MoDOT Efforts

Several approaches involving MoDOT-specific data and research are discussed in the next items: AASHTOWare analysis, laboratory testing, Task 2 modeling of actual field data, and district experiences and costs.

7.3.1 AASHTOWare Analysis

From Chapter 5 (Sub-task 5D), the AASHTOWare analysis of the longevity of 1-in. surface leveling mixes revealed that the program considered initial IRI the most significant factor, along with existing roadway condition and AADTT. Other factors that were important to a lesser extent were climate, subgrade, existing thickness, and overlay quality. Considering the variable types and ranges of input used in the analysis, the overall average life of 1-in. overlays across the state was predicted as 12.5 years. In a comparison to actual MoDOT overlays, the software tended to significantly overestimate overlay life. The overlay lives predicted from AASHTOWare cannot be used for trigger tables per se, but the insight provided by the analysis is useful for creating an evaluation system.

7.3.2 Laboratory Testing

As presented in Chapter 6, laboratory tests of rutting and stripping showed that poor and marginal quality BP-1 mixes lasted 44% and 54%, respectively, as long as a good quality mix. Marginal quality was defined as using marginally acceptable materials; Poor quality was using marginal quality materials, then pushing the mixes to the extreme limits of field tolerances. The number of Hamburg load applications to failure cannot be used directly for trigger tables per se, but the insight provided by the analysis is useful for creating an evaluation system. The quality of the overlay mix under laboratory testing was shown to be more important to longevity than the AASHTOWare analysis would imply.

7.3.3 MoDOT Field Experience

7.3.3.1 Task 2 Modeling

Six models were developed in Task 2 for prediction of IRI: three family models, for use as surrogates for specific route deterioration curves in cost effectiveness calculations, and three treatment models, for prediction of service lives and cost effectiveness calculations: 1-in. HMA overlays on Full-Depth asphalt pavements, 3¾-in. HMA overlays on concrete pavements (Composite pavements), and chip seals on Full-Depth pavements. These models can be re-arranged to solve for Surface Age, which can be viewed as a prediction of service life at certain terminal IRIs (e.g. 140 and 170 in./mile). Every observation (row) in each dataset was a "homogeneous section" as discussed in Volumes II and III in this study. Homogeneity was defined as having no change in surface type (e.g. overlays or chip seals, bridges, etc.) and no change in speed (speed limits, stop signs, etc.).

7.3.3.1.a Full-Depth Asphalt Family Model
The Asphalt Full-Depth family model is displayed as Eq. 7.1:

$$\ln[IRI] = 3.2047+0.0082896*IRI_o+0.042714*SA+0.0009721*IRI_t+0.0046686*FT+0.044608*\ln[Pclay]-0.086607*LstTrtThk \quad \text{(Eq. 7.1)}$$

Where:
IRI = IRI at any time, in./mile
SA= surface age, yrs
IRI_0 = initial IRI after treatment, in./mile
IRI_t = terminal IRI prior to overlay, in./mile
FT= number of freeze/thaw cycles per year
Pclay = amount of clay in subgrade, %
LstTrtThk = last treatment thickness, in.

7.3.3.1.b Concrete Family Model
The Concrete family model is displayed as Eq. 7.2:

$$\ln[IRI] = -737.6002 + 1.53927*SA + 7.4635*DP01 + 2.3945*DT32 + 0.64656*P200 \quad \text{(Eq. 7.2)}$$

Where:
IRI = IRI at any time, in./mile
SA = surface age, yrs
DP01 = number of days with precipitation greater than 0.01 in. per year
DT32 = number of freezing days per year
P200 = minus #200 sieve material in the subgrade, %

7.3.3.1.c Composite Family Model
The Composite family model is displayed as Eq. 7.3:

$$IRI = 3.6259 + 0.0053057*IRI_t + 0.059198*SA - 0.36468*IRI_{improv} + 0.0053319*DT32 \quad \text{(Eq. 7.3)}$$

Where:
IRI = IRI at any time, in./mile
SA= surface age, yrs
IRI_0 = estimated initial IRI after overlay, in./mile
IRI_t = terminal IRI prior to overlay, in./mile
IRI_{improv} = IRI_t/IRI_o
DT32 = number of freezing days per year

The model should be viewed with caution because most of the composite sections in the present report's 3¾-in. overlay data base were just a few years old and had not reached the end of their service lives.

7.3.3.1.d Full-Depth Asphalt Family 1-in. Overlays

For 1-in. HMA overlays on Full-Depth asphalt pavements (solving for SA):

$$SA = (\ln[IRI_T]-3.2547-0.0065029*IRI_0-0.0013964*IRI_t-0.0034073*FT-0.055036*\ln[Pclay])/0.039867 \quad \text{(Eq. 7.4)}$$

Where:
SA = surface age, yrs
IRI_0 = initial IRI after overlay, in./mile
IRI_t = terminal IRI prior to overlay, in./mile
FT= number of freeze/thaw cycles per year
Pclay = amount of clay in subgrade, %
IRI_T = target terminal IRI threshold, in./mile

As with all regression equations, caution must be exercised when attempting to predict beyond the extent of the dataset that was used to derive the equation; in this case the maximum IRI was about 170. Using various combinations of actual minimum and maximum values (in the Central District) of IRI_0, FT, Pclay, IRI_t, and IRI_T in Eq. 7.4, a range of service lives (actually intervals between treatments) were predicted, as shown in Table 7.11. The theoretical best case would be starting with a very smooth overlay (low IRI_0) on an existing pavement that is in relatively good shape (low IRI_t,) a local climate with a relatively low FT, a very good granular subgrade soil, and letting the roadway go to an IRI_T of 170 in./mile; service life is predicted to be 26.7 years (the chances of all this actually occurring simultaneously are slim, but this demonstrates the maximum "possible"). The theoretical worst case is starting with a rough new overlay (high IRI_0) on a rough existing pavement with a relatively high FT local climate, a poor subgrade soil, and limiting IRI_T to 140 in./mile; service life is predicted to be 2.6 years. More realistic mid-range values of all the variables at an IRI_T of 140 in./mile renders a life of 12.6 years (not an average value). In these examples, for the pavements in the dataset, the quality of materials and construction is unknown. This would include the quality of surface preparation undertaken.

Table 7.11 – Estimated service life of 1-in. overlays from Missouri smoothness, climate, and subgrade data from regression Eq. 7.4

Condition	IRI_o (in./mile)	IRI_t (in./mile)	FT (cycles/yr)	Pclay (%)	IRI_T (in./mile)	SA (yrs)
Best	55	96	55	12	170	26.7
Average	86	142	65	40	150	14.4
Average	86	142	65	40	140	12.6
Worst	126	208	74	55	140	2.6
Restore*	86	142	65	40	142	13.0
Restore*	86	150	65	40	150	14.1

* Restore means IRI_T ends up where it started (IRI_t)

The 2.6-to-26.7 year predicted range is in fairly good agreement with the literature, which reports thin overlay pavement extension lives of 3 to 23 years (Wu et al. 2010). Using Missouri mid-range values for subgrade soil, climate, IRI_o, and IRI_t, the 12.6 year mid-range prediction fits the data from Peshkin et al. (5 to 12 years) as shown in Table 7.7. In a synthesis report on thin asphalt overlays, Watson and Heitzman (2014) report that in Ohio it takes nearly 16 years for the smoothness level to return to the same IRI of the existing pavement prior to the overlay. Using Eq. 7.4, for Missouri mid-range values, the age to reach IRI_t is calculated as 13.0 years at an IRI_t = 142 in./mile, and 14.1 years for an IRI_t = 150 in./mile. These two lives are actually Treatment Lives (last existing $IRI_t = IRI_T$). The other calculated lives are really RSL_{AT}s ($IRI_T > IRI_t$). This is shown in Table 7.11. MoDOT's Pavement Direction manual estimated 1-in. overlay lives at 8 to 12 and 12 to 15 years for minor roads, depending on traffic level. Watson and Heitzman give a reported range of 7 to 11 years. The actual data from the present study's dataset shows that the average 1-in. overlay life (not necessarily TL or SLE; reasons for terminating the overlay life are unknown) for all Full-Depth asphalt pavements (in the Central District) is 10.0 years (5.0 to 15.8 years range in the dataset), with an associated average IRI_t of 142.1 in./mile. Again, this data seems to follow the national and regional trend (Table 7.7).

For all the sections in the Full-Depth pavement data set, the increase in IRI per year had an average of 5.455. However, this is a linear rate. The change in IRI would be expected to become more non-linear over time, thus longevity at longer service lives could not be extrapolated from the 5.455 rate, i.e., the linear rate would give a somewhat over-predicted life. Plotting SA vs. IRI with IRI_o at one month normalized to the field data average of 86, the overall equation of the best-fit line is:

$$SA = 6.66916652 \cdot \ln((IRI - 68.98686)/17.690206) \qquad \text{(Eq. 7.5)}$$

Using Eq. 7.5, the predicted lives for initial IRIs of 140 and 170 in./mile are shown in Table 7.12. The non-linear values (Eq. 7.5) agree well with the 10.0 year average computed from the actual data (average IRI_t of 142.1 in./mile). The linear rate, however, over-predicts lives as terminal IRI increases. Thus, although useful, simple linear rates of change can be somewhat misleading at higher service lives. The relationship (Eq. 7.5) is useful when determining benefit-cost ratios, which is discussed in a later section.

Table 7.12 – Predicted lives of 1-in. based on surface age only

IRI_t (in./mile)	SA (non-linear) (yrs)	SA (linear) (yrs)
140	9.3	9.9
170	11.7	15.4

7.3.3.1.e Full-Depth Asphalt Family 1-in. Overlays: AASHTOWare Comparison

AASHTOWare predictions for data similar to Table 7.11 are shown in Table 7.13:

Table 7.13 – Comparison of estimated service life of 1-in. overlays from AASHTOWare predictions to regression estimation

IRI_0 (in./mile)	IRI_t (in./mile)	Climate (FT) (cycles/yr)	Pclay (%)	IRI_T (in./mile)	AASHTOWare SA (yrs)	Field Data Prediction SA (yrs)
55	96	55	12	140	32.5	21.8
55	142	65	40	140	30.0	17.7
55	208	74	55	140	27.5	14.1
86	96	55	12	140	13.5	16.7
86	142	65	40	140	13.5	12.6
86	208	74	55	140	11.0	9.1
126	96	55	12	140	0	10.2
126	142	65	40	140	0	6.1
126	208	74	55	140	0	2.6

It appears that in general, AASHTOWare over-predicts the lives of the 1-in. overlays, except at high initial IRIs where the program has difficulty.

7.3.3.1.f Full-Depth Asphalt Family Chip Seals

The model developed in Task 2 using actual MoDOT field data for chip seals was re-arranged to solve for Surface Age, which can be viewed as a prediction of service life at certain terminal IRIs (e.g. 140 and 170 in./mile).

$$SA = [49.0979 - 0.85358*IRI_0 - 0.16403*IRI_t - 0.75390*FT + IRI_T]/2.8642 \qquad \text{(Eq. 7.6)}$$

Where:
SA= surface age, yrs
IRI_0 = initial IRI after chip seal, in./mile

IRI_t= terminal IRI prior to chip seal, in./mile
FT= number of freeze/thaw cycles per year
IRI_T= target terminal IRI threshold, in./mile

As with all regression equations, caution must be exercised when attempting to predict beyond the extent of the dataset that was used to derive the equation; in this case the maximum IRI was about 140. Using various combinations of actual minimum and maximum values (in the Central District) of IRI_0, FT, IRI_t, and IRI_T, a range of service lives were predicted, as shown in Table 7.14. The theoretical best case would be starting with a very smooth newly-treated pavement (low IRI_0), on a relatively good existing pavement (low IRI_t), a relatively good local climate (low FT), and letting the roadway go to an IRI_T of 170 in./mile; the upper boundary condition service life is predicted to be 34.1 years (the chances of all this actually occurring simultaneously are slim, but this demonstrates the maximum “possible”). The theoretical worst case is starting at a moderately high IRI_0, with a relatively high FT, and limiting IRI_T to 140; the lower boundary condition service life is predicted to be 1.3 years. More realistic mid-range values of variables (IRI_o, IRI_t, and FT) and at an IRI_T of 140 in./mile render a predicted life of 6.7 years. In these examples, for the pavements in the dataset, the quality of materials and construction is unknown.

Table 7.14 – Estimated service life of chip seals from Eq. 7.6

IRI_0 (in./mile)	IRI_t (in./mile)	FT (cycles/yr)	IRI_T (in./mile)	SA (yrs)
78	80	55.3	170	34.1
119	109	67	170	17.1
119	109	67	140	6.7
126	119	78.1	140	1.3

The 1.3 to 6.7 year predicted range is in good agreement with the literature, which reports chip seal service lives of 3 to 8 years (Wu et al. 2010; Peshkin et al. 2011b; ILDOT 2009). In a survey of state/province DOTs, Pierce and Kebede break down the service lives of chip seals among new construction, seals-on-seals, and seals-on-asphalt pavements, as well as functional classification of the roadways (Pierce and Kebede 2015). This data is shown in Table 7.15. The overall range is 4 to 17 years, with averages around 6 to 7 years. Better pavement support and less traffic render longer service life.

Table 7.15 – Survey of chip seal service lives based on support and functional classification*

Statistic	Over Existing Chip Seal (yrs)				Over Existing Asphalt Pavement (yrs)			
	Collector Urban	Collector Rural	Local Urban	Local Rural	Collector Urban	Collector Rural	Local Urban	Local Rural
Minimum	4	4	4	4	6	5	6	5
Maximum	8	10	7	15	10	17	10	17
Average	6.3	6.6	6.1	7.5	7.4	7.3	7.1	7.4

*(Pierce and Kebede 2015)

MoDOT's Pavement Direction manual estimated chip seal lives at 3 to 7 years for minor roads, depending on coarseness of the aggregate. A simple SA vs IRI relationship (discussed next) with IRI_o normalized to the average IRI_o gives lives of 5.3, 6.2, and 7.8 years at IRI_T's of 135, 140, and 150 in./mile, respectively. The actual data from the present study data sets shows that the average chip seal life for all Full-Depth asphalt pavements (in the Central District) is 5.1 years (2.6 to 8.6 years range in the data set), with an average IRI_t of 108.8 in./mile.

Plotting SA vs. IRI with IRI_o normalized to field data average 115.6, the overall equation of the best-fit line is:

$$SA = [(IRI - 115.59588)/1.5731067]^{0.667} \quad \text{(Eq. 7.7)}$$

Using Eq. 7.7, the predicted lives for terminal IRIs of 140 and 170 are shown in Table 7.16. The non-linear value at IRI_o of 140 agrees well with the 5.1 year average computed from the actual field data where actual average IRI_t was 108.9 in./mile.

Table 7.16 – Predicted lives of chip seals, non-linear

IRI_T (in./mile)	SA (non-linear) (yrs)
140	6.2
170	10.6

7.3.3.1.g Composite 3¾-in. Overlay

Although, according to the MoDOT Engineering Policy Guide (EPG), any overlay exceeding 1¾-in. is not defined as a preventive treatment and is thus outside the scope of this research project, there were essentially no segments for Composite pavements in the Central District (indeed, most of the state) on minor routes that had overlays this thin, i.e., most overlays in the data set were thicker and thus came under the definition of "minor rehabilitation" (MoDOT 2014). Nonetheless, models were developed for Composite pavements; however, only one overlay thickness set of segments (3¾-in.) had sufficient data to develop a stand-alone overlay model. For 3¾-in. HMA overlays on concrete pavements:

$$SA = [\ln(IRI_T) - 2.4382 - 0.016750*IRI_0 + 0.44938*\ln(IRI_{improv}) - 0.0097153*DT32\,]/0.065681 \quad \text{(Eq. 7.8)}$$

Where:
SA = surface age, yrs
IRI_0 = initial IRI after overlay, in./mile
DT32 = number of freezing days per year
$IRI_{improv} = IRI_t/IRI_o$
IRI_t= terminal IRI prior to overlay, in./mile
IRI_T = target terminal IRI threshold, in./mile

As with all regression equations, caution must be exercised when attempting to predict beyond the extent of the dataset that was used to derive the equation; in this case the maximum IRI was about 150 in./mile. Using Eq. 7.8, assuming average climate, IRI_t conditions, and using an IRI_o of 86 (same as 1-in. overlays), the predicted service life is 12.6 years. This is similar to a range (11 to 14 years) that was determined in a study in for Louisiana DOT for similar pavements (Khattak et al. 2013). MoDOT's Pavement Direction manual did not list estimated 3¾-in. overlay lives for minor routes, but for major roads, the estimate was 7 to 10 years. The Missouri Guide for Pavement Rehabilitation (Donahue 2002) estimated 10 years on NHS routes (varying thicknesses). It would be expected to be somewhat longer for the lower volume roads represented in the present study. Unfortunately, most of the composite sections in the present report's 3¾-in. database had not reached their terminal IRI, thus a comparison of predicted-to-actual overlay life could not be made. Just three sections reached IRI_t and were chip sealed, at an average age of 5 years. For all the sections in the Composite pavement data set (all overlay thicknesses), the change in IRI per year was an average of 2.0 (range was 0.5 to 4.8). However, this linear rate was only determined for a few years because of the newness of the overlays. The shape of the change-in-IRI per year would be expected to become non-linear after some time, thus longevity could not be extrapolated using the 2.0 rate.

Of the 13 routes that were in the Composite dataset, the HMA mixes were as follows:

- Seven segments- Superpave: usually SP125 over SP190
- Two segments- plant mix: BP-1 over BB
- One segment- plant mix: BP-2 over BB
- One segment- plant mix: BP-1 over BP-1
- One segment- plant mix: BP-3 over BP-1
- One segment- surface leveling

where BB = bituminous base and BP = bituminous pavement.

7.3.3.2 District Experience

Although the Districts have programmed pavement lives, District personnel say these values are really used as place-holders for programming purposes.

7.3.3.3 Summary of Data-Derived MoDOT Treatment Performance Periods

Family models were determined for Full-Depth Asphalt, Concrete, and Composite pavements. The Composite model represented a range of treatments from chip seals to 3¾-in. overlays. Treatment performance periods were determined for 1-in. surface leveling overlays and chip seals on Full-Depth Asphalt pavements, and 3¾-in. overlays on Composite pavements. Input for each model can be obtained from Table 7.17. Table 7.18 shows some subgrade soils and climate data necessary for computation of the models.

Table 7.17 – Input for family and treatment models

Required Information	Equation	Sources
IRI_o after treatment applied	7.1 for Full-Depth 7.3 for Composites 7.4 for 1-in. overlays 7.6 for chip seals 7.8 for 3¾-in. overlays	Experience with similar pavement condition-contractor-materials; if no experience available, use 55 for extremely smooth, 86 for average conditions, 126 for less than ideal smoothness (1-in. overlays); 17, 119, and 126 (chip seals); 39, 56, and 70 for 3¾-in. overlays on PCC
IRI_T target IRI threshold	all	Typical choices: 135, 140, 150, 170
IRI_t before treatment applied	7.1 for Full-Depth 7.3 for Composites 7.4 for 1-in. overlays 7.6 for chip seals 7.8 for 3¾-in. overlays	ARAN Inventory tables and SS Pavement
DT32	7.2 for Concrete 7.3 for Composites 7.8 for 3¾-in. overlays	Table 7.18; Fig. 3.26 from Task 1 report; NCDC website
DP01	7.2 for Concrete	Table 7.18; Fig. 3.25 from Task 1 report; NCDC website
FT	7.1 for Full-Depth 7.4 for 1-in. overlays 7.6 for chip seals	Table 7.18; AASHTOWare
P200	7.2 for Concrete	Testing of samples from the project site; MoDOT Soils & Geology section records; ASU website or USDA website (see Task 1 report for use of these websites and data); Table 7.18
Pclay	7.1 for Full-Depth 7.4 for 1-in. overlays	Testing of samples from the project site; MoDOT Soils & Geology section records; ASU website or USDA website (see Task 1 report for use of these websites and data); Table7.18
LastTrtThk	7.1 for Full-Depth	ARAN Inventory tables and SS Pavement

Table 7.18 - Subgrade and climate data

		Climate Data					Soils Data					
County	Travelway	DP01	DT32	AFI(50)	F/T	Geologic Areas	P200	PI	LL	GI	Pclay	PSwell
Boone	MO 124	70.5	105.2	939	66.8	GlacPlains	91	28	52	28	40	6.8
Boone	RT E	69.0	101.8	897	64.6	GlacPlains	64	29	52	16	42	7.6
Boone	RT N	68.3	102.1	873	66.4	GlacPlains	96	18	36	18	25	1.8
Boone	RT HH	69.7	103.4	908	65.9	GlacPlains	84	27	48	22	40	6.2
Butler	US 67	70.1	92.3	372	67.0	SE Lowlands	53	5	17	0	20	0.1
Callaway	RT F	71.0	111.0	928	67.1	GlacPlains	91	28	52	28	40	6.8
Callaway	RT C	71.6	111.7	888	72.0	GlacPlains	91	28	52	28	40	6.8
Callaway	RT B	70.2	112.7	967	66.3	GlacPlains	84	27	50	24	41	6.3
Callaway	RT D	67.3	111.4	864	68.3	GlacPlains	68	25	45	15	41	5.2
Camden	MO 7	63.5	89.1	576	60.1	Ozarks	46	17	40	4	37	1.9
Camden	RT J	63.6	89.3	553	57.9	Ozarks	53	22	45	10	45	4.1
Cole	RT C	69.5	100.6	770	74.4	Ozarks	74	25	49	19	47	5.7
Cole	RT E	69.6	99.3	759	73.0	Ozarks	61	30	53	16	45	8.7
Cooper	MO 135	68.0	106.2	877	61.6	GlacPlains	98	25	46	27	36	4.8
Cooper	RT J	67.8	103.7	798	55.3	GlacPlains	98	25	46	27	36	4.8
Cooper	RT M	68.1	106.9	857	64.4	GlacPlains	90	16	34	17	23	1.3
Cooper	MO 87	68.8	107.1	866	62.9	GlacPlains	96	18	36	18	25	1.8
Crawford	RT M	72.6	101.7	593	66.6	Ozarks	18	6	20	0	12	0.1
Dent	MO 32	72.3	92.0	538	62.4	Ozarks	28	16	40	0	33	1.5
Dent	RT K	67.9	94.0	527	61.1	Ozarks	28	16	40	0	33	1.5
Gasconade	MO 28	73.3	110.8	685	66.0	Ozarks	62	29	53	16	32	6.5
Gasconade	MO 19	73.2	112.3	664	68.5	Ozarks	51	28	50	11	42	7.0
Gasconade	RT Y	72.8	111.8	702	67.4	Ozarks	49	25	47	9	40	5.1
Grundy	MO 6	66.1	128.3	1210	69.3	GlacPlains	72	22	34	14	34	3.4
Grundy	US 65	65.4	127.7	1290	69.6	GlacPlains	65	20	36	10	31	2.6
Howard	MO 240	69.2	105.8	882	64.9	GlacPlains	95	30	50	31	32	7.0
Howard	MO 3	69.6	108.3	886	65.0	GlacPlains	71	28	47	18	40	6.8
Howard	MO 87	69.3	110.2	903	64.9	GlacPlains	82	21	41	17	33	3.0
Laclede	MO 32	65.4	92.3	554	57.8	Ozarks	47	0	0	6	39	0.0
Laclede	MO 64	64.2	90.2	574	58.8	Ozarks	44	22	44	8	44	4.0
Laclede	RT J	68.0	91.3	572	59.6	Ozarks	66	20	46	12	45	3.2
Lawrence	MO 174	69.8	92.5	622	60.4	WestPlains	45	21	43	6	38	3.2
Miller	MO 17	66.6	94.1	695	62.9	Ozarks	60	28	50	15	55	8.5
Moniteau	MO 5	66.0	99.5	752	63.3	Ozarks	62	29	53	16	45	8.0
Monroe	US 24	69.5	103.9	1030	65.8	GlacPlains	91	28	52	28	40	6.8
Morgan	MO 52	65.2	97.1	682	59.4	Ozarks	62	29	53	16	45	8.0
Morgan	RT W	65.2	97.4	725	58.5	Ozarks	63	33	56	20	49	11.6
Osage	RT T	72.5	100.8	736	65.9	Ozarks	61	30	53	16	45	8.7
Osage	MO 133	71.5	99.6	734	69.5	Ozarks	61	30	53	16	45	8.7
Pettis	US 50	66.9	105.3	904	53.3	GlacPlains	98	25	46	24	36	4.8
Phelps	RT BB	74.3	98.3	611	69.3	Ozarks	34	17	35	6	27	1.6
Phelps	RT F	73.5	96.5	585	67.6	Ozarks	18	6	20	0	12	0.1
Phelps	US 63	74.7	97.2	652	66.1	Ozarks	61	30	53	16	45	8.7
Phelps	US 63	75.0	104.3	675	66.1	Ozarks	42	13	33	6	28	0.9
Pulaski	RT T	68.6	92.8	536	58.8	Ozarks	53	22	45	10	46	4.1
Pulaski	MO 17	69.0	93.5	583	61.3	Ozarks	66	20	46	12	45	3.2
Pulaski	MO 133	69.5	93.6	576	61.5	Ozarks	66	20	46	12	45	3.2
Schuyler	US 63	66.2	118.2	1265	78.1	GlacPlains	95	32	55	34	40	9.4
St. Francois	MO 8	71.0	101.7	627	65.9	St.Francis	92	13	35	12	30	0.9
St. Francois	MO 32	70.6	101.0	603	67.0	St.Francis	92	13	35	12	30	0.9
Washington	MO 21	69.9	102.1	563	69.6	Ozarks	35	18	39	1	33	2.1
Washington	MO 47	68.8	101.3	649	65.0	Ozarks	34	23	45	2	38	4.1
Washington	MO 185	70.9	109.2	629	68.9	Ozarks	35	18	39	1	33	2.1

7.3.4 Costs-MoDOT Data

MoDOT unit costs for treatments considered in this study are listed in Table 7.19, in addition to generic unit costs found in Table 7.9. Additional information on costs are discussed in Volume II of this study. MoDOT sources include the Pavement Tool, Sharepoint, and district maintenance spreadsheets, among others.

Table 7.19 – MoDOT unit costs of various treatments

Treatment	Cost ($/ centerline mile)	
	SW District	Pavement Maintenance Direction Report
Chip seals	18,000; 14,000-21,000	8000 (fine); 10,000 (coarse)
Onyx slurry seal	18,000	
Micro-surfacing		35,000
UBAWS		60,000
Thin overlay: 1¾-in. Superpave 1¾-in. BP-1 1¼-in. BP-2 1-in. SL	 75,000 70,000-80,000 55,000-63,000 50,000-58,000; 45,000-55,000 (Central District)	 70,000 25,000
Structural overlay		170,000 (major)
Fog seals		2200 (1200 <400 ADT)
Cold Mix overlay		13,000
Partial Overlay		2000

7.4 Trigger Matrices and Decision Trees

Trigger tables from MoDOT and other states were considered when the trigger tables for this study were developed.

7.4.1 MoDOT Matrices and Decision Trees

Two trigger decision trees/matrices that MoDOT uses or is considering using are found in the Engineering Policy Guide and the Pavement Maintenance Direction report. In section 413 of the EPG, a decision tree shows the strategy for preservation (Fig. 7.7). Basically, once the decision has been made that the specific project is appropriate for preventive maintenance and not structural rehabilitation, the proper preventive treatment process begins. However, issues such as minor rutting may require attention first, such as milling or milling-and-filling, before a surface treatment or thin overlay is applied. Then the extent of environmental cracking is determined. Next, severity of surface wear is judged. At this point, the two distress types are treatable by crack treatment, or a combination of crack treatment and surface treatments or thin overlays. Surface treatments are less than 1-in. thick, while thin overlays are 1-to-1¾-in. thick. The EPG and the Pavement Direction report discuss a selection of surface treatments including crack sealing and filling, profile milling, fog sealing, scrub sealing, chip sealing, micro-surfacing, partial overlays, and UBAWS. Matching specific distress type/severity/extent to treatment is left to the pavement selection specialist. However, certain treatment candidates are targeted for certain IRI-PASER combinations. Table 7.20 is excerpted from the Direction report. The Direction report describes IRI and PASER rating thresholds for making decisions in regard to the point at which intervention is triggered. Based on roadway functional classification and traffic volume, IRI thresholds of 140, 170, and 220 come into play, as well as PASER ratings of 3 or 5, depending on functional classification and AADT.

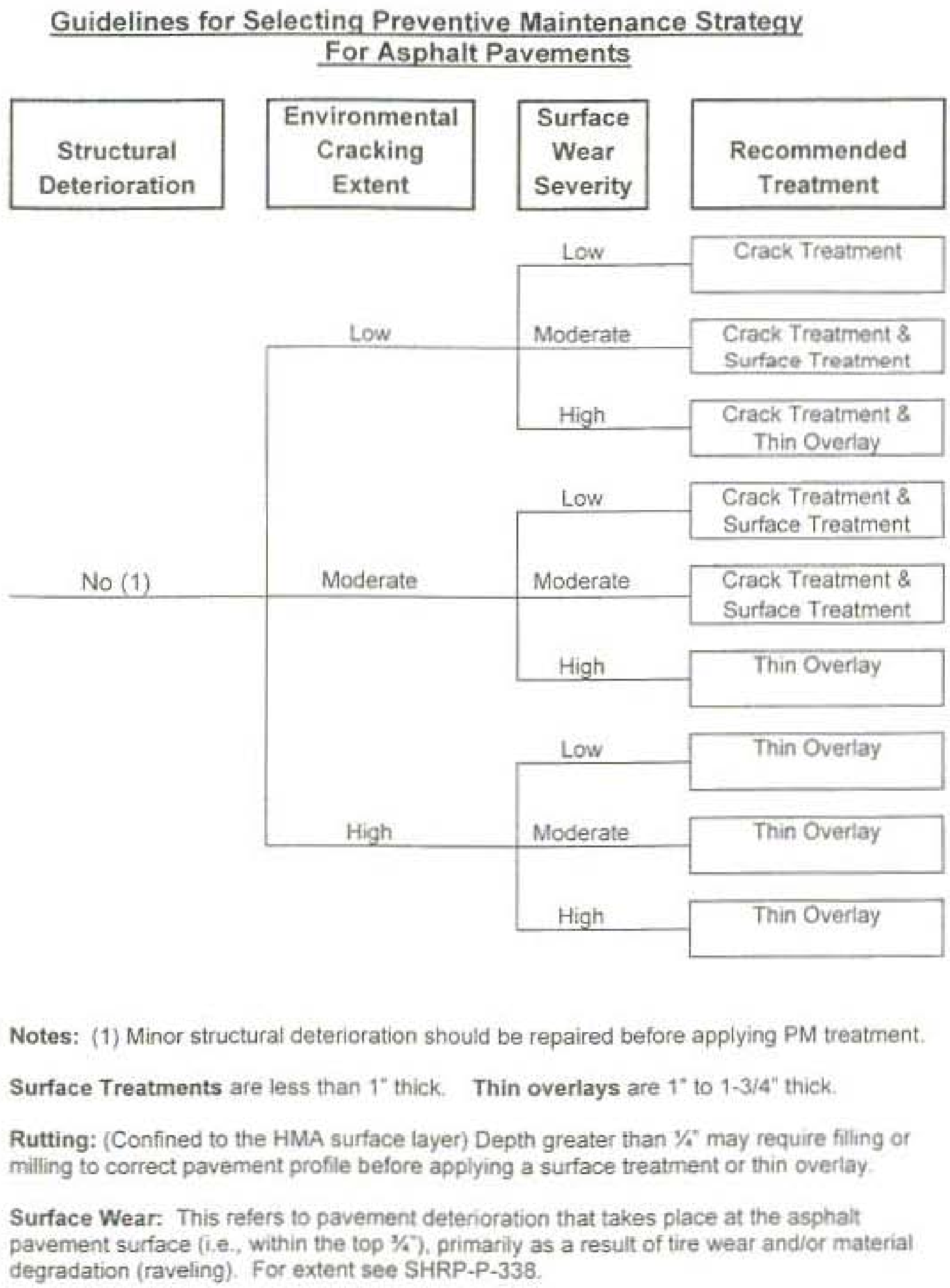


Fig. 7.7 – MoDOT EPG preventive maintenance decision tree.

Table 7.20 - MoDOT treatment selection table from Pavement Maintenance Direction

MoDOT Treatment Selection Based on Roadway Condition			
Route Type Based on ADT	**Overall Condition of Roadway**		
	Good Condition (Goal - Keep in Good Condition)	**Poor Condition** (Goal - Bring to Good Condition)	**Poor Condition** (Goal – Keep Safe and Passable)
Interstate	UBAWS 1 ¾” AC Overlay	Alt. Bid Rehab/Constr. 1 ¾” – 3 ¾” AC Overlay	N/A
Major Routes	Microsurface UBAWS 1 ¾” AC Overlay Chip Seal only if ADT < 2,500	Alt. Bid Rehab/Constr. 1 ¾” – 3 ¾” AC Overlay 1” CLC	N/A
Regionally Significant Minor Routes	Microsurface UBAWS ≤ 1 ¾” AC Overlay Chip Seal	1” – 2 ¾” AC Overlay 1” CLC	N/A
Minor Routes > 400 ADT	Chip Seal Fog Seal	1” CLC Cold-Mix Overlay Hot/ Cold Mix Partial Overlay	Cold-Mix Overlay Hot/ Cold Mix Partial Overlay
Low Volume Routes < 400 ADT	Chip Seal Fog Seal	Cold-Mix Overlay Hot/ Cold Mix Partial Overlay	Cold-Mix Overlay Hot/ Cold Mix Partial Overlay

By using the distress conditions described in PASER (Fig. 7.1) and in the EPG tree, PASER ratings have been aligned with the distresses and associated treatment recommendations, shown in Table 7.21 and later in Table 7.22. It should be noted that the Direction has a different definition of “Good” condition than does PASER (Walker et al. 2002b), which becomes problematic when interpreting Table 7.21. In the Direction report, road conditions are either “Good” or, by default, “Not Good”. The Direction considers “Good” as a PASER rating of 5-and-above for minor roads with greater than 400 AADT, and a minimum of 3 for less than 400 AADT, whereas PASER would consider a 5 and a 3 as “Fair” and “Poor”, respectively. The Direction treatment selection recommendations do not line up in every case with PASER or most of other published recommendations, nor with the EPG decision tree. Table 7.21 compares treatment recommendations from PASER (Walker et al. 2002b), Peshkin et al., the EPG, and the Direction.

Table 7.21 – Treatment recommendation comparisons

PASER Figs. 7.1, 7.2		Common Recommendations Table 7.1	EPG Fig. 7.6	Pavement Direction Table 7.20		
				Significant Minor	>400ADT	<400ADT
7	CT	CT, SS, MS, CS; UBAWS, TOL, M&F, CIR	CT			
6	Seal coat	CT, SS, MS, CS; UBAWS, TOL, M&F, CIR	CT & ST	CS, FS, MS, UBAWS, TOL	FS, CS	FS, CS
5	Seal coat, TOL	CT, CS; UBAWS,TOL, M&F, CIR, HIR, PM	TOL	CS, FS, MS, UBAWS, TOL	FS, CS	FS, CS
4	SOL, recycle	CT, CS; UBAWS, TOL, M&F, CIR, HIR, PM	NA	TSOL, TOL	TOL, POL	FS, CS
3	Repair plus SOL, recycle	TOL, CIR, HIR, PM	NA	TSOL, TOL	TOL, POL	FS, CS

CT = crack treatment; ST= surface treatment (general); FS= fog seal; SS= slurry seal; MS= micro-surface; CS= chip seal; UBAWS= ultrathin bonded asphalt wearing surface; TOL= thin overlay; M&F= mill and fill; CIR= cold in-place recycling; HIR= hot in-place recycling; profile milling; SOL= structural overlay; TSOL= thin structural overlay; POL= partial overlay; NA= not applicable

In general, the EPG and PASER agree. Peshkin et al. are more specific about treatments than PASER, but do not recommend structural overlays (probably because this type of treatment is for rehabilitation, whereas Table 7.1 ("Common Recommendations") is supposed to be just for preservation) - yet a high amount of alligator fatigue cracking and rutting would indicate distress beyond that of preservation treatments. The Direction's recommendation for significant minor routes lines up pretty well with PASER and Table 7.1, but for PASERs of 4 and 3 where structural distress occurs, for "regular" minor routes, structural overlays are not candidates and in fact, for low volumes routes the recommendations are strictly chip seals and fog seals. This is borderline not recommended by anybody else, but it is understood that under the present economic situation, first cost dominates.

Tables 7.22a and 7.22b depict the trigger tables that reflect current thinking at MoDOT for minor roads with greater than 400 AADT and less than 400 AADT, respectively. The tables were developed from the decision tree in the EPG, the Pavement Direction matrix, and knitted together with PASER ratings at distress description interpretations. The tables list preservation-type treatments only; the assumption is that there are no load-associated distresses and that any minor rutting (< ¼ in.) has been taken care of by filling or milling. Surface treatment candidates include fog seals, chip seals, micro-surfacing, and UBAWS. Overlays are thin overlays.

The category where IRI is between 140 and 170 is probably associated with a PASER range of 3-5 (Poor, Fair), so structural deterioration is either imminent (4) or already pronounced (3); if pronounced (IRI > 170), minor or major rehabilitation would be required to restore the pavement rating to “Good”. The Direction suggests thin overlays (< 2 in.), cold mix overlays, partial overlays, and thin structural overlays (2-3 in.). The category where IRI is above 170 is probably associated with a PASER range of ≤ 3 (Poor), so structural deterioration is evident. At IRI above 185 and at PASER ratings of 1-2, structural deterioration is severe and reconstruction would be required, or else the road would be allowed to subside into a keeping-safe-only mode via partial patching and cold mix overlays.

Table 7.22a – MoDOT Pavement Preservation Treatment Triggers combined from EPG and Pavement Direction for asphalt minor roads with greater than 400 AADT, with estimated PASER ratings. PASER rating of 4 but IRI <170 is not shown

Condition (PASER)				IRI <140 (in./mile)				IRI 140-170 (in./mile)		
				8	7	6	5	7	6	5
Environmental Cracks (≥5)	LS	Surface Wear	L (6-7)	DN	CT	CT & ST		CT	CT & ST	
			M (6)	DN		CT & ST			CT & ST	
			H (5)	DN		CT & TOL	CT & TOL		CT & TOL	CT & TOL
	MS		L (6-7)	DN	CT&ST	CT & ST		CT & ST	CT & ST	
			M (6)	DN		CT & ST			CT & ST	
			H (5)	DN		TOL	TOL		TOL	TOL
	HS		L (6-7)	DN	TOL	TOL		TOL	TOL	
			M (6)	DN		TOL			TOL	
			H (5)	DN		TOL	TOL		TOL	TOL

LS = Low Severity; MS = Moderate Severity; HS = High Severity
L = Low; M = Moderate; H = High
DN = Do Nothing; CT = Crack Treatment; ST = Surface Treatment; TOL = Thin Overlay

For minor routes with less than 400 AADT**,** the definition of “good” is lowered in the 2010 Pavement Direction to a PASER of 3 for an IRI of 170-220. Because of the different definitions of “Good” in association with distress levels, it is somewhat difficult to match treatments to physical condition. The Direction dictates that HMA thin overlays are no longer an option for pavements in Good condition, and surface treatments are limited to chip seals and fog seals. One interpretation of the Direction is that PASER ratings of 3-4 can receive cold mix overlays and partial patching to elevate the rating.

Table 7.22b – MoDOT Pavement Preservation Treatment Triggers for asphalt minor roads with less than 400 AADT, with estimated PASER ratings

Condition (PASER)				IRI <170 (in./mile)				IRI 170-220 (in./mile)		
				8	7	6	5	7	6	5
Environmental Cracks (≥5)	**LS**	**Surface Wear**	**L (6-7)**	DN	CT	CT & ST		CT	CT & ST	
			M (6)	DN		CT & ST			CT & ST	
			H (5)	DN		CT & ST	CT & ST		CT & TOL	CT & ST
	MS		**L (6-7)**	DN	CT&ST	CT & ST		CT & ST	CT & ST	
			M (6)	DN		CT & ST			CT & ST	
			H (5)	DN		CT & ST	CT & ST		CT & ST	ST
	HS		**L (6-7)**	DN	CT&ST	CT* & ST		ST	ST	
			M (6)	DN		CT* & ST			ST	
			H (5)	DN		CT* & ST	CT* & ST		ST	ST

LS = Low Severity; MS = Moderate Severity; HS = High Severity
L = Low; M = Moderate; H = High
DN = Do Nothing; CT = Crack Treatment; ST = Surface Treatment
*At high levels of cracking may not be candidates for crack treatment

7.4.2 Other States

Other state DOT decision trees/matrices were consulted and compared to Table 7.22, such as that of the Ohio DOT. Interestingly, although in tree form, the Ohio DOT setup was quite similar to MoDOT's in strategy and treatment types (but did not include slurry seals). In other words, ODOT broke their pavements into categories by surface type, functional classification, and traffic level. Within that, the overall condition index guided the treatment choice, with individual distress severity and extent fine-tuning the choices, i.e. for a given overall condition number, distress would steer the choice into thin overlay (TOL) or surface treatments (Watson and Heitzman 2014).

Numerous other state DOT trigger matrices and decision trees were consulted; most were in terms of 100 point overall condition indices and DOT-derived individual distress indices, which made it very difficult to compare to MoDOT's PASER system.

7.4.3 Proposed MoDOT Trigger Tables/Trees

In general, treatment decisions can be based on smoothness, distress-related overall condition indices, and/or specific distress parameters (type-extent-severity). Ideally, treatments should be tied to specific distresses. Condition indices and smoothness are a step away from linking cause–and–effect. For instance, a certain condition index may be attributed to any one of a variety of causes (see Table 7.1), but not all treatments will fix all those causes. The wrong treatment could be specified. The same could be said of smoothness. There are some individuals that are very good with working with IRI-only or overall condition index-only, but not everybody has that depth of experience. Thus, at the minimum, specific distresses should somehow be tabulated, even if only from a visual survey.

The most common type of threshold for triggering treatments is with some sort of overall condition index. MoDOT is using PASER, along with IRI. Unfortunately, at the time of this study interval, there was insufficient data to perform PASER modeling; only IRI data was available. In an effort to match PASER thresholds to corresponding IRI thresholds, Figs. 7.8 and 7.9 were developed from asphalt-surfaced pavement field data of minimum, median, and maximum values of IRI and PASER ratings and treatment service lives. The figures are rough placeholders until more data is collected in the future. Approximate levels of IRI corresponding to PASER thresholds are shown, along with recommended treatments. For example, when IRI has increased above approximately 120, this would correspond to a PASER of 7—time to do crack treatments. Around an IRI of 170, the pavement has passed from a Good rating to a Poor, dropped below a PASER of 5, and structural deterioration is occurring. Time for a rehabilitation of some sort. The IRI thresholds are also required for cost effectiveness analysis of candidate treatments, discussed later.

The general approach recommended herein is: knowing IRI and PASER rating, determine several candidate treatment types. Then, from a visual survey of the proposed project, using Tables 7.1 and 7.22, treatments that are not appropriate are discarded for the specific distress types, extents, and severities. Finally, using a cost effectiveness approach, the remaining treatments are ranked.

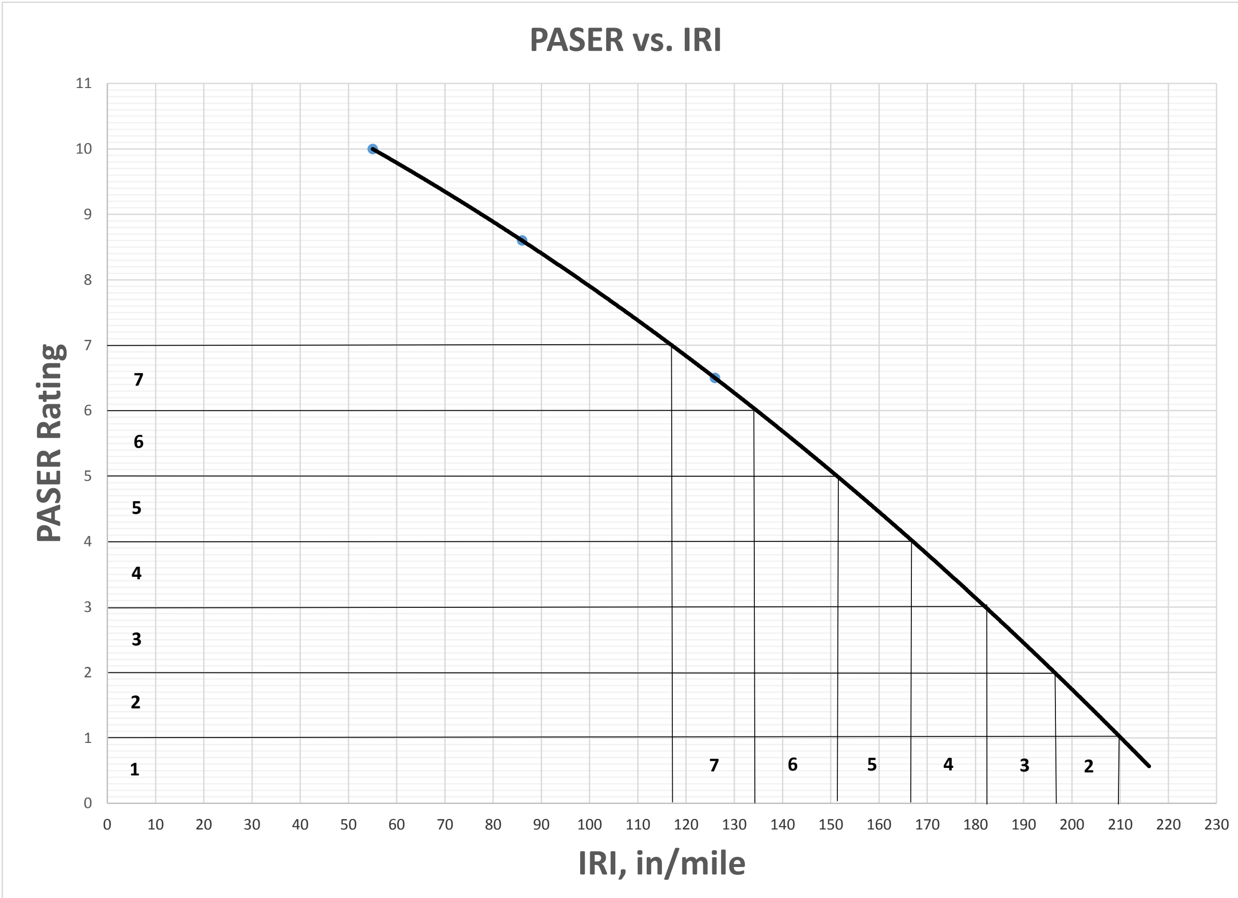


Fig. 7.8 – Approximate IRI vs. PASER ratings, MoDOT field data.

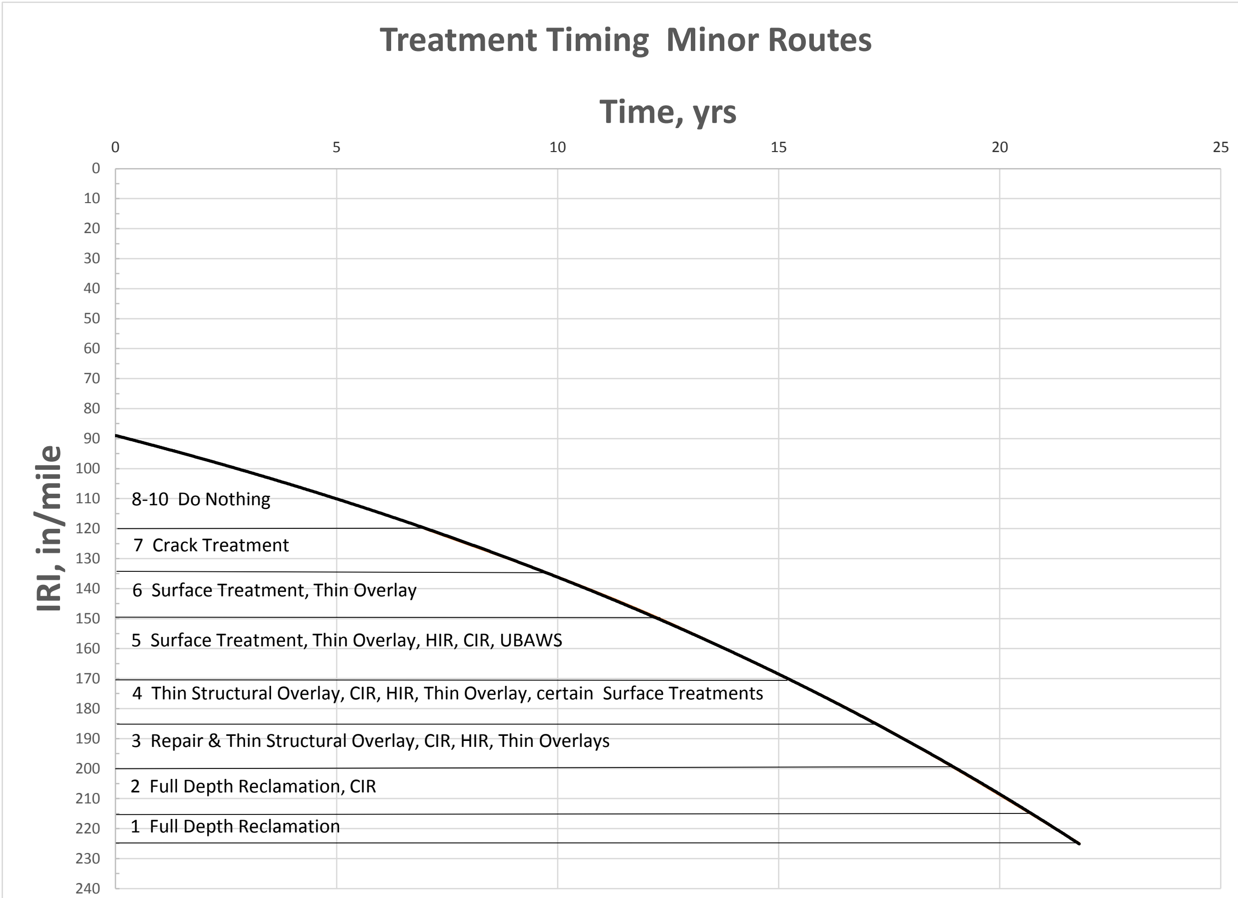


Fig. 7.9 – IRI vs. time with recommended treatment and rehabilitation types for asphalt surfaced roadways with associated PASER values.

7.5 Homogeneous Section Condition Plots

Ideally, all MoDOT routes will eventually be divided into homogeneous sections. Each section will have its own condition plots of real data for IRI and PASER rating deterioration. The fitted curves can be extended to the action threshold of choice; one commonly used threshold is where reconstruction is the only option. Ideally, each curve would be constructed from real IRI or PASER data; an example site-specific extended IRI curve is shown in Fig. 7.10. In use, when a section is being analyzed for a life cycle-type analysis, the deterioration curves plus a variety of possible treatment strategies would be plotted over an analysis period of, say, 30 years.

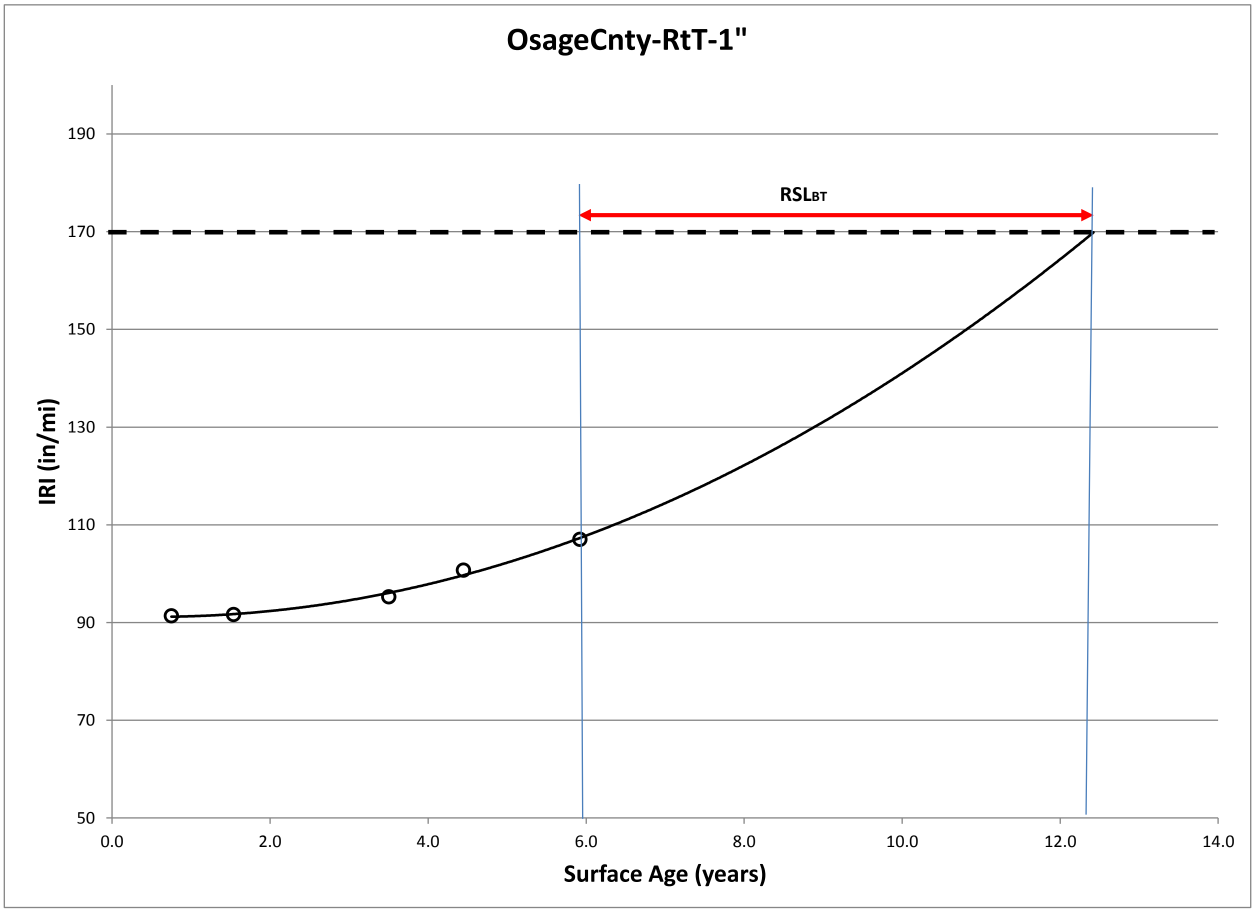


Fig. 7.10 – Site-specific IRI deterioration curve.

When available, a PASER rating deterioration curve would also be constructed for the segment, and RSL_{BT} determined for each of the two curves. The shortest RSL would be chosen with which to go forward (see discussion below).

Sometimes, however, there will not be sufficient data to plot a site-specific curve, especially in the early going of setting up this part of a PMS. In order to plot a real-data curve, the Colorado DOT recommends at least five condition points, with an R^2 of at least 0.50. So, in the case of an insufficient number of points, in lieu of a “real” curve, a family curve can be substituted until sufficient data is available. The family curve is one fitted to many other similar sections. In the present study, family curves have been presented for Full-Depth Asphalt, Composite, and Concrete pavements. For instance, the model represented by Eq. 7.1 can be used for a given asphalt route’s homogeneous section; the IRI prediction from Eq. 7.4 will be tailored to that section via local FT, Pclay, LstTrtThk, IRI_t, and IRI_o data.

Either way (family curve or real-data curve), once the IRI-time curve is plotted and extended to the threshold-of-choice (IRI_T), the analysis for treatment life can be done—this can be used later in Equivalent Annual Cost (EAC), B/C, or RSL cost-effectiveness calculations (see the following sections for a more complete discussion of cost effectiveness analysis). Various treatment strategies can be tried (e.g. an initial 1-in. overlay at the beginning of the analysis period, a chip seal at 8 years, another 1-in. overlay at 12 years, and so forth. RSL_{BT}, RSL_{AT}, and

SLE can be then calculated as discussed previously in Item 7.1.10 (SLE = $RSL_{AT} – ESL_{BT}$). Then an EAC or B/C analysis performed. Next another treatment strategy can be tried, and a B/C analysis is done again. Finally the alternate strategies B/C's are compared, and one treatment chosen, say, for the greatest B/C. If one is analyzing a lot of routes and strategies, it will become necessary to invoke the use of a software program specifically designed to do this. These programs (such as Deighton's dTIMS) are capable of optimizing the selection, based on such methods as an "incremental B/C" analysis. This level of analysis is beyond the scope of this study.

7.6 Cost Effectiveness

The simplest method of evaluating several candidate treatments via cost effectiveness is by the *Equivalent Annual Cost (EAC)* method (Peshkin et al. 2011b). The *benefit-cost ratio method (B/C)* is more involved, but it gives more information. The *Remaining Service Life* concept has also been used. All are presented next.

7.6.1 EAC

The EAC is calculated as the unit cost divided by the performance life of the treatment. Table 7.23 uses cost data from Table 7.9 plus performance lives from Table 7.7 for calculation of EAC values. These are example-only values used as placeholders. In actual use, MoDOT maintenance decision-makers should use the most current or projected unit costs and service lives available to them. The generic performance lives in Table 7.23 can be replaced by performance lives applicable specifically to Missouri, as developed in the sections above for 1-in. overlays and chip seals on asphalt pavements and 3¾-in. overlays on concrete pavements, and as are determined by MoDOT in the future. For a given project site, use of the prediction equations can fine-tune the treatment life (and hence EAC, B/C, or RSL) for climate, subgrade, existing condition, and expected starting smoothness. Judgement will have to be used to further fine-tune treatment lives for factors such as construction quality and materials quality. Item 7.3.2 indicated that poor quality materials and construction inspection could shorten pavement life by up to about 50%.

Technically, it is preferred that the "performance" life (denominator) in the EAC calculation should be the Service Life Extension (SLE), not the Treatment Life (TL). However, there are several reasons why the TL is used. First, the TL is less difficult to determine: the number of years it takes for the smoothness level to return to the same IRI of the existing pavement prior to the overlay is easily calculated via the models developed in this study, setting $IRI_t = IRI_T$. When "service lives" are reported in the literature, it is difficult to assess what exactly that means. Also, if the curves are parallel to each other, then TLE is close to the SLE. Thus, in this report, TL will be used in EAC and B/C calculations.

Table 7.23 – Equivalent Annual Costs for various treatments

Treatment	Unit Cost Range ($)	Unit Cost Average ($/yd^2)	Perf Life Range (yrs)	Perf Life Average (yrs)	EAC ($/yd^2/yr)
Asphalt-Surfaced					
Crack filling	0.10-1.20/ft	N/A	2-4	N/A	N/A
Crack sealing	0.75-1.50/ft	N/A	2-8	N/A	N/A
Slurry sealing	0.75-1.00/yd^2	0.88	3-6	4.5	0.20
Micro-surfacing (single-course)	1.50-3.00/yd^2	2.25	4-7	5.5	0.41
Chip seal Single course	1.50-2.00/yd^2	1.75	4-6 5-7 6-8	5.0*	0.35
Chip seal Double course	N/A	2.62**	N/A	10.0**	0.26**
UBAWS	4.00-6.00/ yd^2	5.00	7-12	9.5	0.53
Thin overlay	4.00-6.00/ yd^2	5.00	7-10	8.5*	0.59
Mill & thin overlay	5.00-10.00/ yd^2	7.50	7-10	8.5	0.88
Hot in-place recycling (excluding overlay)	2.00-7.00/ yd^2	4.50	6-15	10.5	0.43
Cold in-place recycling (excluding overlay)	1.25-3.00/ yd^2	2.12	5-13	9.0	0.24
Profile milling	0.35-0.75/ yd^2	0.55	0	N/A	N/A

Concrete-Surfaced					
Joint resealing	1.00-2.50/ft	N/A	4-8 (Hot pour asphalt) 8 (Silicone)	N/A	N/A
Crack sealing	0.75-2.00/ft	N/A	4-8	N/A	N/A
Diamond grinding	1.75-5.50/ yd^2	3.62	8-15	11.5	0.31
Diamond grooving	1.25-3.00/ yd^2	2.12	0	N/A	N/A
Partial depth patching	75.00-150.00/ yd^2 (patched area; equivalent 2.25-4.50/ yd^2 based on 3% surface area patched)	3.38	5-15	10	0.34
Full depth patching	75.00-150.00/ yd^2 (patched area; equivalent 2.25-4.50/ yd^2 based on 3% surface area patched)	3.38	10-15	12.5	0.27
Dowel bar retrofitting	25.00-35.00/bar (equivalent 3.75-5.25/ yd^2, based on 6 bars per 12-ft crack/joint and crack/joint retrofits every 30 ft)	4.50	10-15	12.5	0.36
UBAWS	4.00-6.00/ yd^2	5.00	7-12	8.0	0.62
Thin overlay	3.00-6.00/ yd^2	4.50	6-10	8.0*	0.56

*Data from the present study shows for MoDOT roadways, chip seals average 6 years and thin overlays and modest structural overlays average 12-13 years

** Double chip seals' estimated 1.5 cost and 2 times life of single chip seals

7.6.2 Benefit-Cost Ratio

The benefit-cost ratio method of evaluating different treatments involves taking the benefit derived from the treatment and dividing by its cost. "Benefit" is defined as the additional performance derived from the treatment. It is the net area (sum of all treatments in the analysis period) under the treatment-time curves, as depicted in Fig. 7.11. The y-axis would be

IRI or PASER ratings, and the x-axis would be the years of the analysis period. Different families and treatment service lives would be on the x-axis, plotted at the expected timings of the treatments.

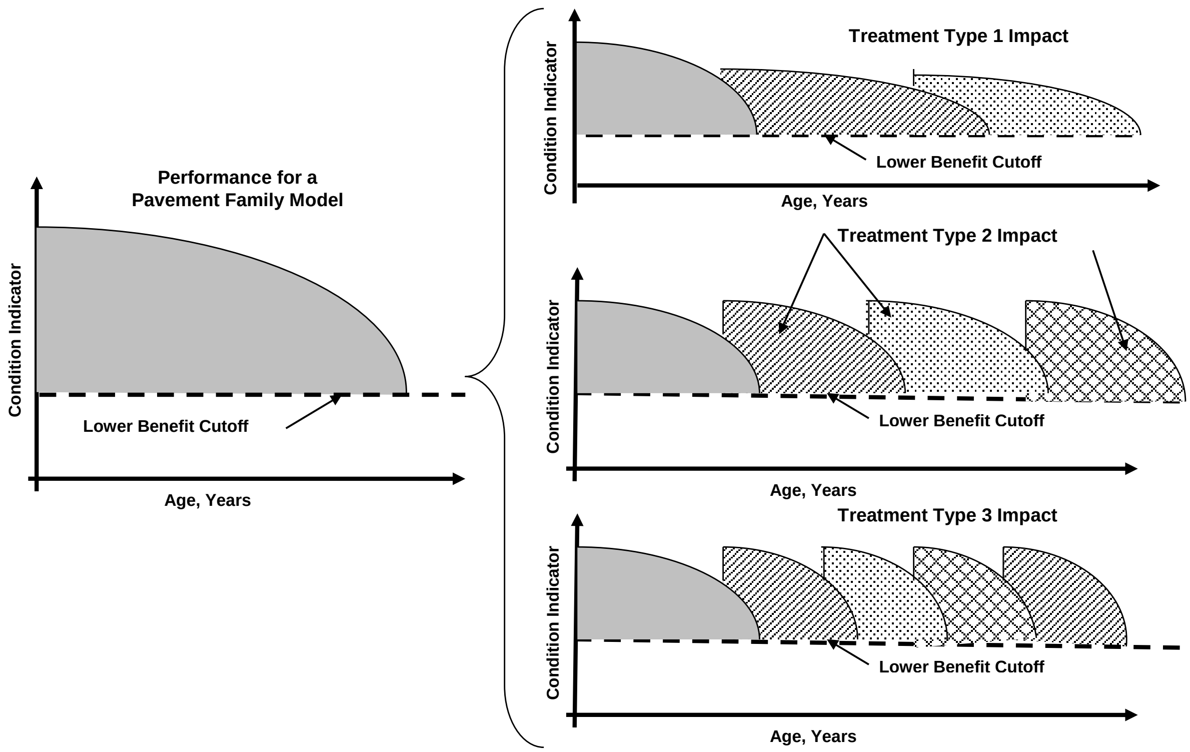


Fig. 7.11 – Impact of various treatments (1, 2, 3) on Pavement Family Performance Curve. Different treatments can have different costs and result in different periods of acceptable performance.

The costs are as described in Item 7.6.1. If desired, a Life Cycle Cost Analysis (LCCA) approach can be conducted to generate the cost associated with a particular treatment. The future projected costs of each treatment can be converted to present-day costs via a specified discount rate (typically 3-5%) before summing all the treatments. Most state DOTs have a standard procedure for conducting LCCA. Also, the FHWA has software called "RealCost" for such calculations (FHWA 2004). In any event, in a comparison of several appropriate treatments, the one with the highest B/C would be the most cost-effective (Smith and Harrington 2014).

Fig 7.12 shows an example B/C analysis for 1-in. overlays for a 30-year analysis period. The first cycle is the Full-Depth Asphalt family model, starting at the field data average IRI_o of 92 in./mile, taken to an IRI_t of 150 in./mile (150 corresponds to a PASER of threshold between 5 and 6, Fig. 7.8). When the PASER drops into the 5 status, the DOT should be planning on a near-future TOL because once the pavement drops to a 4, not only has the pavement lost its "Good" rating, structural damage is beginning to show up. The second curve is for a 1-in. overlay, starting at the field data average IRI_o for 1-in. overlays (86 in./mile), again terminating at an IRI_t

of 150 in./mile (assuming a 10 year life). The third curve is a partial curve (ending the analysis at 30 years), again for a 1-in. overlay, starting at an IRI_o of 86. For area calculation purposes, all curves worst condition threshold was 170 in./mile (dropping to a PASER of 4). The program “TableCurve” was used to find the areas under the IRI prediction curves along with simple geometry. The areas under the curves (benefit) totaled 1744. Dividing by the 1-in. overlay cost (Table 7.23), the B/C is 927.

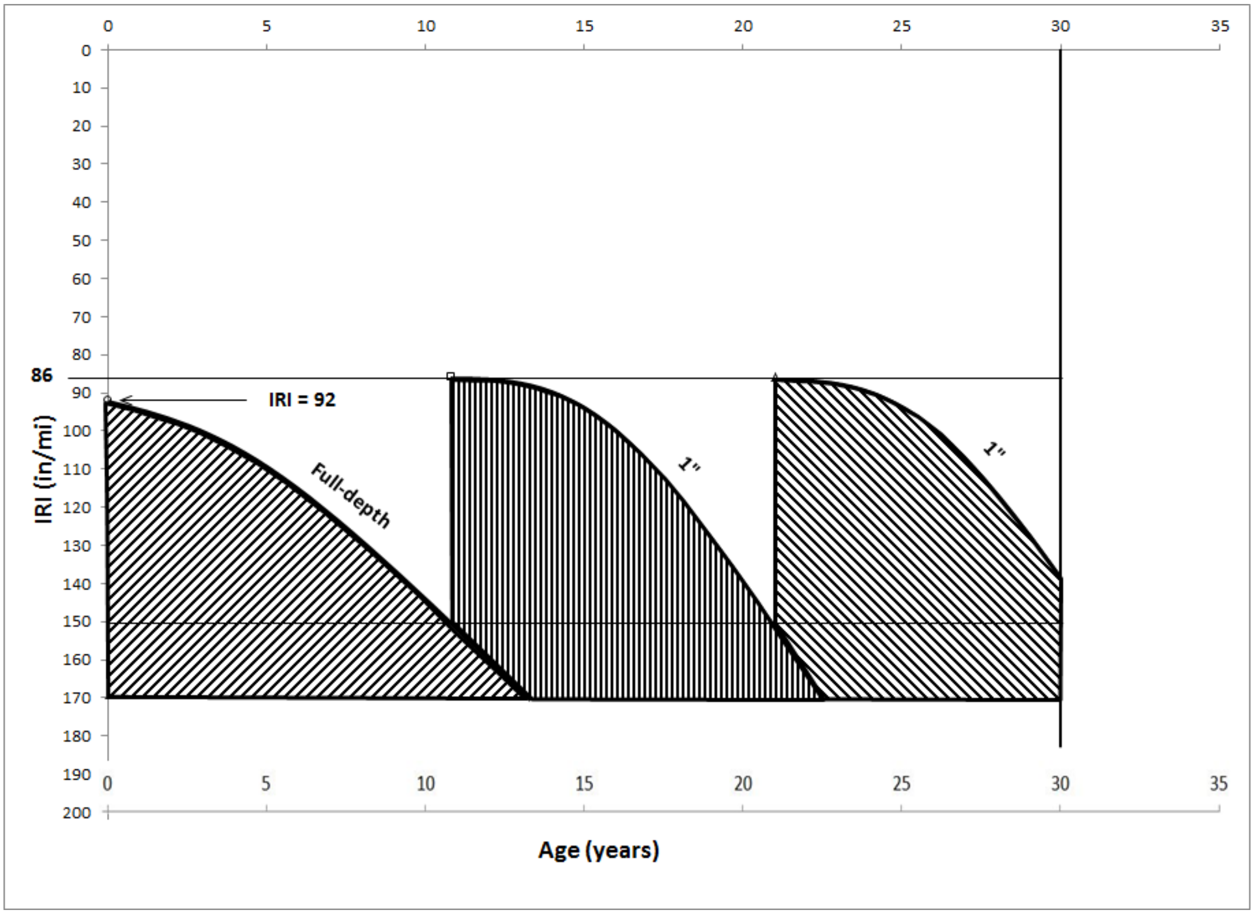


Fig. 7.12 – Example B/C analysis of 1-in. overlay of a Full-Depth asphalt pavement.

Continuing the example, by comparison, Fig. 7.13 is for chip seals. Surface treatments should start earlier on the deterioration curve than TOLs. Again, the first curve is the Full-Depth Asphalt family curve, but this time stopping earlier at a higher terminal IRI_t of 135 (corresponding to a PASER threshold between 6 and 7). The second through fourth curves are full curves for chip seals (using a 5 year life) and the fifth curve is a partial chip seal curve, ending the analysis at 30 years. Each chip seal curve starts at an IRI_o of 116 in./mile (the actual field data-derived average for chip seals) and terminates at 135. The total area under the curves is 1574. Dividing by the chip seal cost (Table 7.23), the B/C is 426. Thus, in this specific example, with these choices for IRI_o and IRI_t (and hence service lives), and the costs from Table 7.23, the best buy (highest B/C) is the 1-in. overlay series. It should be noted that the 1-in. overlays will keep the pavement in a smoother condition than the chip seals for a significant part of the analysis period, and that is a benefit to the motorist, which is not specifically accounted for in an EAC calculation.

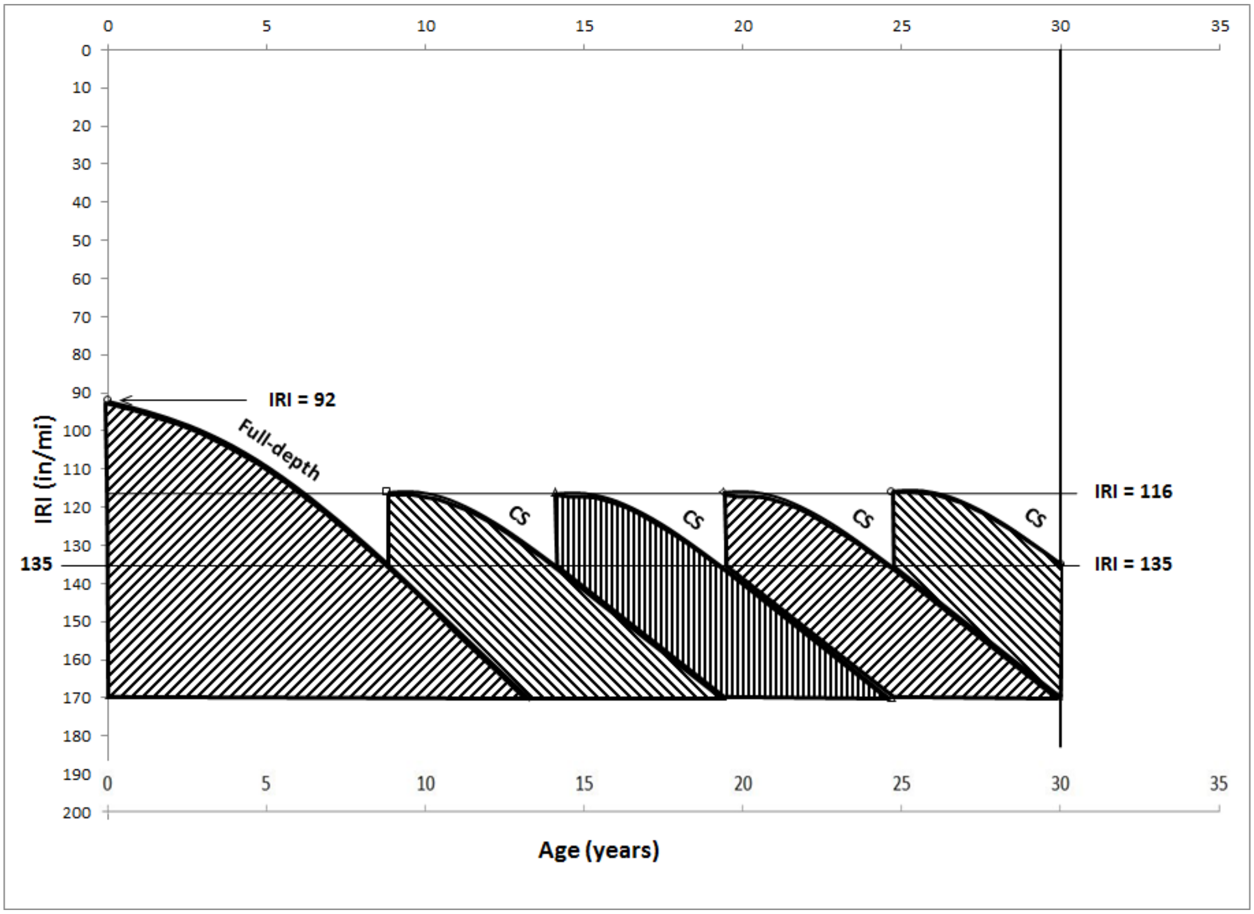


Fig. 7.13 – Example B/C analysis of chip seal treatment of a Full-Depth asphalt pavement.

This was a simplified example of comparing just two different treatment strategies. In reality, there would be numerous possible strategies (combinations of a variety of treatments at different intervals per strategy). The Colorado DOT (CDOT) system generates between 21 and 200 strategies for each of its 3500 segments in its system. With this level of complexity, computer programs would be necessary. CDOT uses Deighton dTIMS (Colorado 2011).

7.6.3 Remaining Service Life

Calculation of RSL has been previously introduced in Item 7.1.10 and Section 7.5. Just as in the B/C method, for any given route/segment, either the actual IRI and PASER data for several years can be plotted (minimum 5 years) and then extended to the threshold-of-choice (e.g. IRI = 170), and the RSL_{BT} determined, or, lacking sufficient data, the appropriate family model can be substituted for the particular location (climate, soil, etc.) and the RSL determined. Then, after doing this for all routes-of-interest, the routes can be ranked by RSL, shortest to longest. A decision would have to be made as to how to choose the routes for treatment. One way would be to treat the routes starting with the shortest RSL. This would be in effect a "worst-first" approach. Or, some other strategy could be used.

7.7 Treatment Selection Process

7.7.1 Selection Process Steps

The treatment selection process for a given project would, in general, follow that shown in Fig. 1.1. A more complete discussion is included in the following steps. The treatment selection process can be used in both programming and for actual project-specific selection. Of course, nothing can replace experience. Data retrieval (Steps 1-3) is presented in detail in Volume II of this study.

Step 1*-*Make an assessment of the functional and structural performance of the existing pavement by retrieval of archived data:

- Annual road condition (ARAN) survey data (overall condition [PASER rating and IRI]. IRI and overall condition are not necessarily indicators of specific forms of distress but can be useful as preliminary identifiers of candidate treatments. *[Data comes from ARAN Viewer and ARAN Inventory surveys, and SS Pavement]*
- Any specific distress types including severity and extent *[ARAN Inventory and SS Pavement]*
- If safety is a specific issue: (friction numbers and crash data)
- If noise is a specific issue (pavement-tire noise data)

Step 2*- *Retrieve site historical data:

- Functional classification: *[from ARAN Inventory and SS-Pavement]*
- Urban or rural, geographic location, traffic access, posted speed limit, pavement family type, age, design life, cross-sectional design, construction records, maintenance and rehabilitation information: materials and thicknesses, drainage features: *[Data from a variety of sources such as the Pavement Tool, Sharepoint, District maintenance spreadsheets, STIP, J-Drive, ragmaps, asphalt summary sheets, historic state highway maps, concrete 2-AA sheets, archived project plan sheets (Z-Drive), and as-builts on ProjectWise and CDs and microfilm]*
- Subgrade soil: *[Data from Table 7.18 (more detail can be found from the websites of ASU and USDA, MoDOT Soils & Geology section records, and concrete 2-AA sheets, as discussed in Volume II)]*
- Weather: *[DT32, DP01, FT data from Table 7.18 (more detail can be found from NOAA website and AASHTOWare)]*

Step 3- ***Retrieve traffic information***: Annual Average Daily Traffic (AADT); percentage trucks or Annual Average Daily Truck Traffic (AADTT)(Commercial Truck Volume): *[Data from ARAN Viewer, SS Pavement, and TR 50 reports]*

Step 4- As necessary, ***conduct various site-specific condition surveys***:

- Visual survey to obtain distress type, severity, and extent:
  - Environmental (thermal) cracking
  - Raveling
  - Bleeding
  - Polishing
  - Longitudinal cold joint cracking
  - Joint reflective cracks
  - Longitudinal edge breakup
  - Stable rutting
  - Structural rutting
  - Corrugations/shoving
  - Depressions/bumps
  - Potholes
  - Substandard Patches
- Drainage survey: minimum of a visual survey:
  - Presence of moisture-related distress
  - Cut/fill depth
  - Transverse slopes (pavement and shoulder)
  - Ditch geometrics (depth, width, longitudinal slope)
  - Drainage effectiveness
- Coring; non-destructive evaluation *[Construction & Materials databases, J-Drive, and ProjectWise]*
- Friction numbers, noise data

Step 5- Combine information from steps 1 through 4 into a "Site Status Report".

Step 6- ***Decide whether the project is a candidate for Preservation or Rehabilitation***, e.g. are the pavement's distresses primarily treatable by preservation methods and there is no excessive distress associated with structural or subsurface materials problems? Fig. 7.9 and Tables 7.1 and 7.2 can be used to decide whether a certain type of distress is appropriate for Preservation or for Rehabilitation; Fig. 7.9 requires IRI and PASER input, while Tables 7.1 and 7.2 require individual distress type, severity, and extent. For instance, such distresses as settlement, heaving/swelling, severe longitudinal wheel path cracking, structural rutting, mix instability rutting, delaminations, corner breaks, and poor subsurface drainage are not listed as candidates for Preservation remediation; rather, these are more appropriately dealt with by Rehabilitation methods. Another clue that a Rehabilitation should be done rather than Preservation is if the rate of IRI change is greater than about 7-8 in./mile per year, the deterioration is likely due to structural or subsurface material issues. Finally, is there a history of pavement problems in this location? Has the pavement passed below the "Good" condition? Affirmative answers would steer the designer into considering rehabilitation.

In order to select the proper treatments and then narrow them down to one or two, the *performance needs* of the project would be evaluated next:

1) The project's targeted performance goals (e.g. improve smoothness only, improve structural condition or enhance structural capacity, improve friction, reduce noise, or improve surface drainage (splash/spray, cross slope)
2) Available funding for alternate treatment times of intervention
3) Traffic level/functional roadway classification
4) Match of the proposed treatment types with the distress type, severity and extent [see below discussion]
5) Appropriate match of treatment to climate (in Deep Freeze zone? [Fig. 7.5])
6) DOT experience with a given treatment (extent and success)
7) DOT practice or district preference (includes maintenance considerations, e.g. behavior during snowplowing)
8) Motorist preferences (e.g. HMA vs. surface treatment)

Construction constraints would also need to be considered:

9) Time of year construction (weather limitations)
10) Geometrics (curves, intersections, curb-and-gutter, etc.)
11) Work zone duration restrictions, e.g. facility downtime: one day, weekend, longer
12) Traffic disruption/control and safety
13) Availability of qualified contractors
14) Availability of good quality materials for a given treatment
15) Availability of specialized equipment and/or materials
16) Environmental considerations (e.g. air quality, recycling/sustainability)

Once it is established that Preservation (as opposed to Rehabilitation) is appropriate, and the performance needs and constraints are determined, with the Site Status Report in hand, Tables 7.22a and 7.22b trigger tables can be used as a guide for ***selection of candidate treatments*** appropriate for certain IRI and PASER ratings for HMA pavements as deemed by MoDOT policy. The treatment categories are not specific beyond “Surface Treatments” and “Thin Overlays”. The tables are used to match general treatment type with level of condition in terms of overall condition (PASER). Determination of specific treatments is presented next.

After a visual survey has been conducted and individual distress levels of extent and severity are determined, one would enter Table 7.1 and ***select several alternate treatments*** appropriate for *each of the distresses individually* for the assigned pavement family. Table 7.2 is the PCC counterpart to Table 7.1. Both of these tables show windows of opportunity in terms of overall condition. From this analysis, a shorter list of *just the treatment types appropriate for all the significant distresses* would be made.

Peshkin et al. recommend to further narrow the list of climate-compatible treatments: areas in the “Deep Freeze” climate zone, such as the northern tier of counties in Missouri. Not recommended are slurry seals, diamond grooving, and thin overlays on PCC, UBAWS on PCC (urban areas). Of course, local experience would take precedence over generic recommendations. Peshkin et al. also note that concrete treatments such as ultra-thin whitetopping (UTW), partial- and full-depth patching, and dowel bar retrofitting have work zone duration restrictions in that these normally take longer than overnight/single-shift.

Step 7- With the appropriate service lives and relative costs per lane mile, **conduct an Equivalent Annual Cost (EAC) analysis, a Benefit/Cost (B/C) effectiveness analysis, or a Remaining Service Life analysis** for each potential treatment. Items #13 and #14 above should be considered. Poor quality materials and construction practices could reduce the expected service lives of the TOL and the chip seal (which are calculated from Eq. 7.4 and 7.6, respectively), which will increase the EAC result.

Service lives of all alternative treatments must be determined. Service lives of 1-in. overlays, chip seals, and 3¾-in. overlays on composite pavements can be predicted from Eqs. 7.4, 7.6, and 7.8. Guidance for input for the equations is in Table 7.17. Calculated lives should be adjusted downward for expected poor quality aggregate or construction (e.g. unfavorable time of year, workforce inexperience, minimal inspection, etc.). One way to accomplish this is by using a conservative (high) value for IRI_o (such as much greater than 86 for 1-in. overlays and much greater than 119 for chip seals).

Service lives can also be determined by assuming a value for service life, based on experience supplemented by information from Table 7.7 and discussion in Sub-items 7.3.3.1.a-d, f, and g.

Generic unit costs can be obtained from Tables 7.9, 7.19, and 7.23, but it would be much preferable to use more current and representative cost information available to MoDOT from the Pavement Tool, Sharepoint, and district maintenance spreadsheets, among other sources. If desired, LCCA can be used to calculate various treatments' overall costs for a programmed (analysis) period in terms of a summed present day cost. EAC is then calculated as the unit cost divided by the service life.

Benefit-cost analyses can also be conducted by calculating the areas under various specific route or family curves and treatment deterioration curves. Specific route performance curves are preferred, but do not exist at present. Therefore, family curves will have to be used. These can be calculated via Eqs. 7.1, 7.2, and 7.3. The treatment performance curves that exist at present are calculated from Eqs. 7.4, 7.6, and 7.8. Other treatment type performance curves should be developed by MoDOT as experience with them is gained. The "benefit" is the net added area under the treatment curve, which does not include the area under the do-nothing part of the existing pavement curve. Decisions have to be made as to calculation of treatment lives, which involve choices about beginning and terminal target IRI or PASER thresholds, which are arbitrary. Table 7.17 and Fig. 7.8 offer advice on IRI_o and IRI_T; IRI_t can be obtained from ARAN and SS Pavement.

The RSL method could also be employed by comparing RSL_{BT}s, which come from the performance curves.

Step 8- Using the calculated cost effectiveness of all treatments and all projects, ***create a network-level (county, region or state-wide) project prioritization list***. Project prioritization could be based on other considerations in addition to benefit/cost.

Information that should be collected each time a treatment is used is listed in Table 7.24.

Table 7.24 – Information to be collected as associated with a project

Route number
Geographic location
Project length
Segment beginning and ending logmiles
Surface type (Pavement Family Type)
Functional Classification
AADT, AADTT or % trucks, truck distribution
Existing pavement cross-section: material types, thicknesses
Climate data: closest weather station, DT32, DP01, FT
Last treatment year (surface age)
Last Treatment Thickness
Last condition survey date
Distress types & trigger values used to trigger the selected treatment
Pavement Condition rating prior to treatment and after (IRI and PASER Rating)
Drainage survey
Costs
Contractor and DOT experience with this treatment: High = treatment used routinely Medium = sometimes used or have been used for 5 years or less Low = not regularly used or in pilot projects
Subgrade soil type and P200, Pclay, PI, etc.

7.7.2 Treatment Selection Example

The project is a rural route in the Northwest District in Grundy County west of Trenton involving a two-lane route with 500 AADT. The existing structure consists of 5 in. of various asphalt mixes and seal coats over some granular base of unknown detail. The last treatment that the road received was a 1-in. surface leveling mix in 2007. Aggregate materials in the area will most likely be used for the surface treatment or overlay asphalt mixes, and are of marginal quality. Typical contractors in the area that would be expected to participate in bidding have reasonable reputations in regard to construction quality.

Details in regard to information sources within MoDOT are presented in Volume II of this study.

Step 1-Make an assessment of the functional and structural performance of the existing pavement by retrieval of archived data. Data from ARAN Inventory and ARAN Viewer surveys indicates the following:

2012: PASER rating = 6; IRI= 145 in./mile
2013: PASER rating = 6; IRI= 150 in./mile

2014: PASER rating = 5; IRI= 155 in./mile

Step 2*- *Retrieve site historical data:
Functional classification: from ARAN Inventory and SS Pavement- the route is a minor route (not regionally significant) with AADT > 400
Rural or Urban: rural
Geographic location: Grundy County, west of Trenton
From a variety of sources such as the Pavement Tool, Sharepoint, District maintenance spreadsheets, STIP, J-Drive, ragmaps, Asphalt Summary sheets, historic state highway maps, and As-Builts, the following three categories can be covered:
Pavement family type: Full-Depth Asphalt
Last surface treatment: 1-in. surface leveling mix in 2007
Cross-sectional design: The existing structure consists of 5 in. of various asphalt mixes over some granular base
Subgrade soil: from Table 7.18 (more detail can be found from the websites of ASU and USDA, and MoDOT Soils and Geology section records, as discussed in Volume II), the subgrade is predominantly an A-7-6 with just a moderate swell potential, Pclay = 34
Drainage: surface-only
Climate: from Table 7.18 (more detail can be found from AASHTOWare) FT= 69.3 cycles per year

Step 3*- *Retrieve traffic information: From ARAN Viewer and SS Pavement, approximately 500 AADT

Step 4*- *Conduct various site-specific condition surveys: A visual survey reveals the following estimated distresses; evaluation of distress extent and severity is aided by Tables 7.1 - 7.3.

Environmental cracking: >10% of area, thermal transverse crack every 10 ft = *Medium severity*
Raveling: 12% of area = *Medium severity*
Bleeding: *none*
Polishing: *none*
Longitudinal cold-joint cracking: 5% with cracks >¼ in. = *Low severity*
Fatigue cracking: ¼ in. wide, 2% of the area = *none-to-Low severity*
Longitudinal cracking in the wheel path: <¼ in. = *Low severity*
Joint reflective cracks: *NA*
Longitudinal edge breakup: >10% loss = *High severity*
Stable rutting: 10% ¼ -½ in. deep = *Medium severity*
Structural rutting: *none*
Corrugations/shoving: *none*
Depressions/bumps: *none*
Potholes: *1 in one segment*
Substandard Patches: *1 in one segment*
Drainage condition: *no outstanding issues with transverse cross slopes and ditches*
Low Friction: *NA*

Noise: *NA*

Step 5- Combine information from steps 1 through 4 into a "Site Status Report".

Step 6- Decide whether the project is a candidate for Preservation or Rehabilitation

The above level and extent of distresses reveals no excessive settlement, heaving/swelling, severe longitudinal wheel path cracking, alligator cracking, structural rutting, mix instability rutting, and subsurface drainage problems. The gain in IRI per year is about 5 in./mile, which is below the cautionary level of 7-8 in./mile. There is no history of pavement problems in this location. The roadway is still in the MoDOT "Good" condition. Thus, the roadway is deemed a candidate for preservation treatments, as opposed to rehabilitation. Even factoring in the 5 in./mile increase in IRI, Fig. 7.9 indicates that the PASER rating will still be 5 in two years, thus the pavement will still be a candidate for preventive maintenance then.

The *performance needs* of the project would be evaluated next:

1) *The project's targeted performance goals:* improve smoothness and improve structural condition. Improvement of friction, reduction of noise, and improvement of surface drainage (splash/spray, cross slope) are not goals of the treatment. This narrowing of the project scope eliminates the need for special mixes (e.g. OGFC for drainage or SMA for noise) or invoking aggregate polishing specifications for friction.
2) *Availability of funding for different treatment times of intervention:* It appears that funding will be available for both different treatment times of intervention (now and in two years).
3) *Traffic level/functional roadway classification needs:* relatively low.
4) *Match of the proposed treatment types with the distress type, severity and extent:* [see below discussion]
5) *Appropriate match of treatment to climate:* project is located in or close to a Deep Freeze zone; however, the existing pavement is not concrete or a composite, so no restrictions are anticipated for any treatment type.
6) *DOT experience with a given treatment:* District experience includes TOL, chip seals, microsurfacing, UBAWS.
7) *DOT practice or district preference:* EPG states that micro-surfacing is somewhat inappropriate for extensive cracking.
8) *Motorist preferences:* typically motorists prefer HMA overlays to chip seals

Construction constraints would also need to be considered:

9) *Time of year construction (weather limitations):* none - anticipated construction mid-summer.

10) *Geometrics (curves, intersections, curb-and-gutter, etc.):* no significant issues.

11) *Work zone duration restrictions e.g. facility downtime: one day, weekend, longer:* typical treatments will not cause more than one day downtime.

12) *Traffic disruption/control and safety:* low volume rural minor road—no anticipated problems.

13) *Availability of qualified contractors:* several in the area for some types of treatments (e.g. chip seals and TOL), but not all (see #15 below).

14) *Availability of good quality materials:* aggregate is only marginally acceptable; this will reduce pavement service lives.

15) *Availability of specialized equipment and/or materials:* none are available for slurry seals, onyx seals, UBAWS, whitetopping, and contractors may not choose to bid on "scratch & seal".

16) *Environmental considerations (e.g. air quality, recycling/sustainability):* rural area; no push for a sustainability demonstration project.

The most prevalent deficiencies are medium severity thermal cracking, medium severity raveling, medium severity stable rutting, low severity longitudinal joint cracking, and high severity edge breakup. From MoDOT's Table 7.22a, with IRI 140-170 and a PASER = 5, two general types of treatments are recommended: CT&ST or TOL.

To obtain a match of specific treatments to specific distresses--From Table 7.1:

For medium severity transverse thermal cracking: appropriate treatments are crack sealing, micro-surfacing, single chip seals, double chip seals, UBAWS, TOL, M&F, HIR, CIR, and whitetopping.

For medium severity raveling: profile milling, slurry sealing, micro-surfacing, single chip seals, double chip seals, UBAWS, TOL, M&F, HIR.

For high severity longitudinal edge breakup: double chip seals, TOL, M&F, CIR, and whitetopping.

For low severity cold joint cracking: crack filling, slurry sealing, micro-surfacing, single chip seals, double chip seals, UBAWS, TOL, HIR, and CIR.

For medium severity stable rutting: profile milling, double chip seals, TOL, M&F, HIR, CIR, and whitetopping.

From the above possible treatments, the treatments appropriate for all four distress types are narrowed to: TOL and double chip seals. Fortunately, both of these are available in the area (see #13 and #15 above).

Step 7- With the appropriate service lives and relative costs per lane mile, **conduct an Equivalent Cost (EAC) analysis, a Benefit/Cost (B/C) effectiveness analysis, or a Remaining Service Life (RSL) analysis** for each potential treatment. Items #13 and #14 in Step 6 above should be considered. Poor quality aggregate will reduce the expected service lives of the TOL and the chip seal (calculated from Eq. 7.4 and 7.6, respectively), which will increase the EAC calculation.

For the 1-in. TOL, using Eq. 7.4, at a FT = 69 cycles/yr, a Pclay = 34, using the median IRI_o from past data: an assumed IRI_o = 86, the existing condition IRI_t = 155, and a target IRI_T = 150 to keep the pavement "Good", the estimated life of a 1-in. TOL is 13.8 years. However, poor quality aggregate will reduce the life up to 55%. From local experience, assuming a 40% loss, the reduced life is approximately 8.3 years.

For the double chip seal, using Eq. 7.4 (which is really for single chip seals), at a FT of 69 cycles/yr, an assumed IRI_o of 100 (double chip seals will probably start out smoother than single seals), an existing condition IRI_t of 155 in./mile, and a target IRI_T = 135 in./mile (planning on re-sealing at an earlier point on the deterioration curve), the estimated life of a single chip seal is 7.4 years. Accounting for the extended life of a double seal, adding 4 years to the life gives 11.4 years. However, poor quality aggregate will reduce the life somewhat. From local experience, assuming a 30% loss, the reduced life is approximately 7.5 years.

EAC: Using average costs from Table 7.22, adjusting the lives as above, double chip seals = $2.62/7.5 years = 0.35; TOL = $5.00/8.3 years = 0.60.

B/C: can also be performed if desired. Again, the reduced service lives calculated above should be used in the area-under-the curves calculations. The use of a computer program would be necessary if multiple treatment scenarios were being analyzed and ranked.

RSL: The RSL method could also be employed by comparing RSL_{BT}'s.

8 SUMMARY and CONCLUSIONS

This report (Volume VI) is part of a seven-volume study done by the Missouri University of Science and Technology and the University of Missouri-Columbia for Missouri Department of Transportation. The research in Volume VI (referred to as Task 5) was conducted by the Missouri University of Science and Technology. The general objective of Task 5 was to provide a manual that MoDOT can use to select the most appropriate pavement maintenance treatment for a given roadway project. The selection procedure includes several alternate cost assessment methods. Task 5 entails the development of pavement treatment trigger tables and the treatment candidate selection process.

The scope of the project was to provide maintenance selection process within the constraints of the present MoDOT system of data collection, storage, and retrieval, as well as the methods of pavement condition evaluation (IRI and PASER), and maintenance selection policies (EPG, Maintenance Direction, District role).

A variety of methods was used to develop an understanding of the most significant variables affecting treatment method performance: discussions with MoDOT personnel, literature search of state and federal DOT experience, AASHTOWare treatment option analysis, laboratory mixture testing, and development of models from MoDOT pavement field data.

The search of other state DOT experiences and procedures (including the four states surrounding Missouri: Illinois, Arkansas, Kansas, and Iowa) resulted in tables of appropriate applications, expected treatment performance lives, costs, and methods to evaluate cost effectiveness. The factors that affect treatment selection are:

- Traffic
- Pavement Condition
- Climate and Weather
- Work Zone Restrictions
- Roadway Geometrics
- Experience with Treatment
- Availability of Good Quality Materials
- Availability of Specialized Equipment and Materials
- Environmental Considerations
- Expected Performance
- Available Funding/Cost

The AASHTOWare treatment option analysis revealed the relative importance of several variables to 1-in. overlay pavement performance. The AASHTOWare analysis of the longevity of 1-in. surface leveling mixes showed that the program considered initial IRI the most significant factor, along with existing roadway condition and AADTT. Other factors that were important but to a lesser extent were climate, subgrade, existing thickness, and overlay quality. Considering the variable types and ranges of input used in the analysis, the overall average life of 1-in. overlays across the state was predicted as 12.5 years. In a comparison to actual MoDOT overlays, the software tended to significantly overestimate overlay life. The overlay lives predicted from AASHTOWare cannot be used for trigger tables per se, but the insight provided by the analysis is useful for creating an evaluation system.

As presented in Chapter 6, Hamburg Loaded Wheel Tester and TSR laboratory tests of rutting and stripping showed that marginal poor quality BP-1 mixes lasted 44% and 54% as long as a good quality mix. Marginal quality was defined as using marginally acceptable materials; Poor quality was using marginal materials, then pushing the mixes to the extreme limits of field tolerances. The number of Hamburg load applications to failure cannot be used directly for trigger tables per se, but the insight provided by the analysis is useful for creating an evaluation system. The quality of the overlay mix was shown to be more important to longevity than the AASHTOWare analysis would imply.

Six models were developed in Task 2 (Volume III) for prediction of IRI: three family models, for use as surrogates for specific route deterioration curves in cost effectiveness calculations, and three treatment models, for prediction of service lives in cost effectiveness analyses: 1-in. HMA overlays on Full-Depth Asphalt pavements, 3¾-in. HMA overlays on concrete pavements (Composite pavements), and chip seals on Full-Depth Asphalt pavements. The model equations can be re-arranged to solve for Surface Age, which can be viewed as a prediction of service life at certain target terminal threshold IRIs (e.g. 140 and 170 in./mile). The variables in the models were those that the literature search predicted would be important: existing pre-treatment condition (IRI_t), initial condition after treatment (IRI_o), traffic (using surface age as a surrogate), climate (DT32, FT, DP01), subgrade soil (P200, Pclay), and last treatment thickness (LstTrtThk), as well as the relationship between IRI_o and IRI_t.

The general approach to treatment selection recommended herein is: for a given project, knowing IRI and PASER rating, several candidate treatment types are determined. Then, from a visual survey of the proposed project, using the trigger tables developed in this report, treatments that are not appropriate for the specific distress types, extents, and severities are discarded, thus narrowing the number of candidate treatments. Finally, using a cost effectiveness approach, the remaining treatments are ranked.

The trigger tables are to be used in series. One table was developed from MoDOT's treatment decision tree in the EPG plus the decision matrix from MoDOT's Maintenance Direction report. The EPG and the Direction were reconciled with each other and with pavement field data gathered for use in Task 2. Once the general type(s) of treatments are determined from the table, a second table derived from other states' experiences is used to choose treatments tailored to specific distresses. The list of specific candidate treatments is narrowed to those that are appropriate for all the distresses. Finally, a cost effectiveness analysis is done. Several approaches are presented, including Equivalent Annual Cost, Remaining Service Life, and Benefit-Cost ratio. The last is probably the best, but usually requires the use of software.

Ideally, all MoDOT routes will eventually be divided into homogeneous sections. Each roadway section will have its own condition plots for IRI and PASER rating deterioration. The fitted curves can be extended to the action threshold-of-choice; one commonly used threshold is where reconstruction is the only option. Ideally, each curve would be constructed from real IRI or PASER data. In use, when a section is being analyzed for a life cycle-type analysis, the deterioration curves plus a variety of possible treatment strategies would be plotted over an analysis period of, say, 30 years. When available, a PASER rating deterioration curve would also be constructed for the segment, and RSL_{BT} determined for each of the two curves (IRI and PASER). The shortest RSL would be chosen with which to go forward (see below).

Sometimes, however, there will not be sufficient data to plot a site-specific curve, especially in the early going of setting up this part of a PMS. In order to plot a real-data curve, the Colorado DOT recommends at least five condition points, with an R^2 of at least 0.50. So, in the case of an insufficient number of points, in lieu of a "real" curve, a family curve can be substituted until sufficient data is available. The family curve is one fitted to many other similar sections. In the present study, family curves have been presented for Full-Depth Asphalt, Composite, and Concrete pavements. For instance, the model represented by Eq. 7.1 can be used for a given asphalt route's homogeneous section; the IRI prediction from Eq. 7.4 will be tailored to that section via local FT, Pclay, LstTrtThk, IRI_t, and IRI_o data.

Either way (family curve or real-data curve), in use, once the IRI-time curve is plotted and extended to the threshold of choice (IRI_T), the analysis for treatment life can be done—this can be used later in Equivalent Annual Cost (EAC), B/C, or RSL cost-effectiveness calculations. Various treatment strategies can be tried (e.g. an initial 1-in. overlay at the beginning of the analysis period, a chip seal at 8 years, another 1-in. overlay at 12 years, and so forth. RSL_{BT}, RSL_{AT}, and SLE can be then calculated as discussed previously in Item 7.1.10 (SLE = RSL_{AT} – ESL_{BT}). Then an EAC or B/C analysis performed. Then another treatment strategy can be tried, and a B/C analysis done again. Finally the alternate strategies B/C's are compared, and one treatment chosen, say, for the greatest B/C. If one is analyzing a lot of routes and strategies, it will become necessary to invoke the use of a software program specifically designed to do this. These programs (such as Deighton's dTIMS) are capable of optimizing the selection, based on such methods as an "incremental B/C" analysis. This level of analysis is beyond the scope of this study.

The following is the procedure that a MoDOT Pavement Engineer or Specialist would use for implementing the *modified pavement management flowchart* (Fig. 1.1). The procedure would be followed for a given proposed road maintenance/preservation/rehabilitation project. The word "retrieve" is used to emphasize that the data, models, and tables to be used would already exist:

Step 1- Retrieve annual road condition survey (e.g. ARAN) data

Step 2- Retrieve site historical data: e.g. materials, thicknesses, subgrade soil, drainage, climate, construction records, etc.

Step 3- Retrieve traffic information: Annual Average Daily Traffic (AADT) and percentage trucks, or Annual Average Daily Truck Traffic (AADTT)(Commercial Truck Volume)

Step 4- Conduct a site-specific condition survey (visual, coring, non-destructive testing)

Step 5- Combine information from steps 1 through 4 into a "Site Status" report. Identify the roadway as a certain "Pavement Family" type (see Table 1.1)

Step 6- With "Site Status", enter appropriate Treatment Trigger Tables and select several alternate treatments (Table 1.2) appropriate for the roadway segment (or assigned Family)

Step 7- With the appropriate “Treatment Impact (Performance) Models,” conduct a cost effectiveness analysis for each potential treatment. Choose the final treatment.

Step 8- Using the calculated cost effectiveness of all treatments and all projects, conduct a network-level (county, region or state-wide) project prioritization list. Project prioritization could be based on other considerations in addition to cost effectiveness

9 RECOMMENDATIONS

1. In regard to thin overlays, the data available for this report was constrained to 1-in. Section 402 surface leveling mixes on Full-Depth Asphalt pavements. As data becomes available, models should be developed for 1¼-in. and 1¾-in. Section 401 plant mix mixtures.

2. In regard to structural overlays, the data available for this report was constrained to 3¾-in. Section 401 plant mixes and 403 Superpave mixes on concrete pavements (thus Composite pavements). As data becomes available, models should be developed for thicker overlays on Concrete and Composite pavements.

3. In regard to surface treatments, the data available for this report was constrained to single chip seals on Full-Depth Asphalt pavements. As data becomes available, models should be developed for double chip seals, slurry seals, micro-surfacing, UBAWS, polymer chip seals, scrub seals, and scratch-and seal applications on Full-Depth Asphalt pavements. The same type of surface treatment models should be developed for Composite pavements as appropriate.

4. All routes should be divided into homogeneous sections. Annual data IRI and PASER should be collected, cleansed, and made available as presented in Appendix C of Volume II (Task 1) and Volume III (Task 2). QA on the data can be done in a method similar to that described in Appendix B of Colorado DOT's PMS manual (Colorado 2011). Site-specific IRI and PASER deterioration curves should be developed for each section. Where sufficient data is not available, family models can be substituted as surrogates until sufficient data is available. RSLs should be calculated, and used in a system such as an SLE comparison, or an incremental B/C method for ranking treatments at the project level, and possibly at the network level. This would entail developing or acquiring software specific to this purpose.

5. More family models should be developed as necessary (see #4 above); potential families are shown in Fig. 1.2.

10 REFERENCES

AASHTO, (2014), "AASHTOWare Pavement ME Design", American Association of State Highway and Transportation Officials, Washington, D.C.

Applied Research Associates, Inc., 2009, "Implementing the AASHTO Mechanistic-Empirical Pavement Design Guide in Missouri - Volume I: Study Findings, Conclusions, and Recommendations", RI04-002, MoDOT, Jefferson City, Missouri, 295 pp.

Applied Research Associates, Inc., 2009, "Implementing the AASHTO Mechanistic-Empirical Pavement Design Guide in Missouri – Volume II: MEPDG Model Validation and Calibration", RI04-002, MoDOT, Jefferson City, Missouri, 89 pp.

Asphalt Institute, "A Basic Asphalt Emulsion Manual", MS-19, Asphalt Institute, Lexington, Kentucky, 230 pp.

Barrette, T. P., (2011) "Comparison of PASER and PCI Pavement Distress Indices," Master's Report, Michigan Technological University, http://digitalcommons.mtu./etds/502, 17 pp.

Colorado, (2011), "Pavement Management Manual", 2009 Draft, Colorado DOT.

Colorado, (2012), "Pavement Management Program Technical Narrative", Colorado DOT, 11 pp.

Dawson, T.A., Baladi, G.Y., Beach, A.C., Dean, C.M., Haider, S.W., and Chatti, K., (2012), 'Impact of Three State Practices on Effectiveness of Hot-Mix Asphalt Overlay', Transportation Research Record, Journal of the Trans. Res. Bd. No. 2292, pp. 52-60.

Donahue, J., (2002). "Missouri Guide for Pavement Rehabilitation", Missouri Department of Transportation, RDT 02-013, 66 p.

FHWA, (2004), "Life Cycle Cost Analysis: RealCost User Manual. RealCost Version 2.1", Federal Highway Administration, Washington, D.C.

George, K.P., (1995), "Pavement Management System: Phase II", University of Mississippi, Mississippi DOT, University, Mississippi, 203 pp.

George, K.P., (2000), "MDOT Pavement Management System: Prediction Models and Feedback System", Final Report, University of Mississippi, Mississippi DOT, University, Mississippi, 149 pp.

Gharaibeh, N.G., Zou, Y., and Saliminejad, S., (2010), "Assessing the Agreement Among Pavement Condition Indices," Journal of Transportation Engineering, V. 136, No. 8, pp. 765-772.

Illinois Dept. of Transportation, (2009), "Pavement Preservation, Ch.52: *Design and Environment Manual"*, Illinois DOT, Springfield, Illinois, 25 pp.

Kent County Road Commission, (2002), “Comparison of Pavement Condition Rating Systems PASER vs PCI”, Kent County Road Commission, Planning Division, Kent County, Michigan, 15 pp.
Khattak, M.J., Baladi, G.Y., and Sun, X., (2009), “Development of Index Based Pavement Performance Models for Pavement Management System (PMS) of LADODT”, 168 pp.

Khattak, M.J., Nur, M.A., Bhuyan, M.R., and Gaspard, K., (2013), “International Roughness Index Models for HMA overlay Treatment of Flexible and Composite Pavements,” *International Journal of Pavement Engineering*, 11 pp.

McGhee, K.H., Mahone, D.C., and Newman, A.D., (1991), “A Pavement Management System for Paved Secondary Roads”, Virginia Dept. of Transportation, Richmond, Virginia, 51 pp.

Mechanistic-Empirical Pavement Design Guide, Interim Edition, (2008), AASHTO, Washington, D.C., 204 pp.

Miller, J.S., and Bellinger, W.Y., (2003), "Distress Identification Manual for the Long Term Pavement Performance Program, 4th Ed.”, Report No. FHWA-RD-03-031,FHWA, McLean, Virginia, 164 pp.

MoDOT, (2010a), "Pavement Maintenance Direction", Maintenance Division, Missouri Department of Transportation, 31 pp.

MoDOT, (2010b), “Maintenance Quality Assurance Performance Indicators Inspectors Rating Manual”, Maintenance Division, Missouri Department of Transportation, 76 pp.

MoDOT, (2011), “Maintenance Tracker Performance Data Report,” Missouri Department of Transportation, Jefferson City, Missouri.

MoDOT, (2014), “Engineering Policy Guide”, Missouri Department of Transportation, Jefferson City, Missouri.

MoDOT, (2015), “Missouri Standard Specifications for Highway Construction”, Missouri Department of Transportation, Jefferson City, Missouri.

Peshkin, D., Smith, K.L., Wolters, A., Krstuovich, J., Moulthrop, J., and Alvarado, C., (2011a), "Preservation Approaches for High-Traffic-Volume Roadways", SHRP 2 Report S2-R26-RR-1, Transportation Research Board, Washington, D.C., 175 pp.

Peshkin, D., Smith, K.L., Wolters, A., Krstuovich, J., Moulthrop, J., and Alvarado, C., (2011b), "Guidelines for the Preservation of High-Traffic-Volume Roadways", SHRP 2 Report S2-R26-RR-2, Transportation Research Board, Washington, D.C., 51 pp.

Pierce, L.M., and Kebede, N., (2015), “Chip Seal Performance Measures- Best Practices”, Applied Pavement Technology, Inc., 82 pp.

Scofield, L., Hennings, C., Varnedoe, S., Healow, S., and Harrington, D., (2011), “Survey of State DOT Trigger Values for Concrete Pavement Preservation”, FHWA Pavement Preservation ETG, 37 pp.

Smith, K., and Harrington, D., (2014), “Concrete Pavement Preservation Guide,” National Concrete Pavement Technology Center, Iowa State University, Ames, Iowa, 304 pp.

South Dakota, (2012), “SDDOT’s Enhanced Pavement Management System”, South Dakota DOT, 58 pp.

Tan, S. (2015), “For Performance Management, Is IRI a Better Indicator?”, Trans. Res. Bd. Standing Committee on Pavement Management Systems, http://blog.pavementmananagementsystems.org/, 3 pp.

Walker, D., Entine, L., and Kummer, S., (2002a), "PASER Asphalt Roads Manual", Wisconsin Trans. Res. Center, Madison, Wisconsin, 28 pp.

Walker, D., Entine, L., and Kummer, S., (2002b). "PASER Concrete Roads Manual", Wisconsin Trans. Res. Center, Madison, Wisconsin, 28 pp.

Watson, D.E., and Heitzman, M., (2014),”Thin Asphalt Concrete Overlays,” *A Synthesis of Highway Practice*, NCHRP Synthesis 464, Trans. Research Board, Washington, D.C., 49 pp.

Wu, Z., Groeger, J.L., Simpson, A.L., and Hicks, R.G., (2010), “Performance Evaluation of Various Rehabilitation and Preservation Treatments”, California Pavement Preservation Center, Chico, CA, 90 pp.

Zimmerman, K., Smadi, O., and Peshkin, D.G., (2011), "Guide to Pavement Management - A Proposed Replacement to the 2001 AASHTO Pavement Management Guide," AASHTO, Washington, D.C., (draft: June 30, 2011), 188 pp.

APPENDIX A: PAVEMENT TREATMENT SELECTION GUIDANCE DOCUMENT

The treatment selection process for a given project would, in general, follow that shown in Fig. 1.1, steps 1- 7.

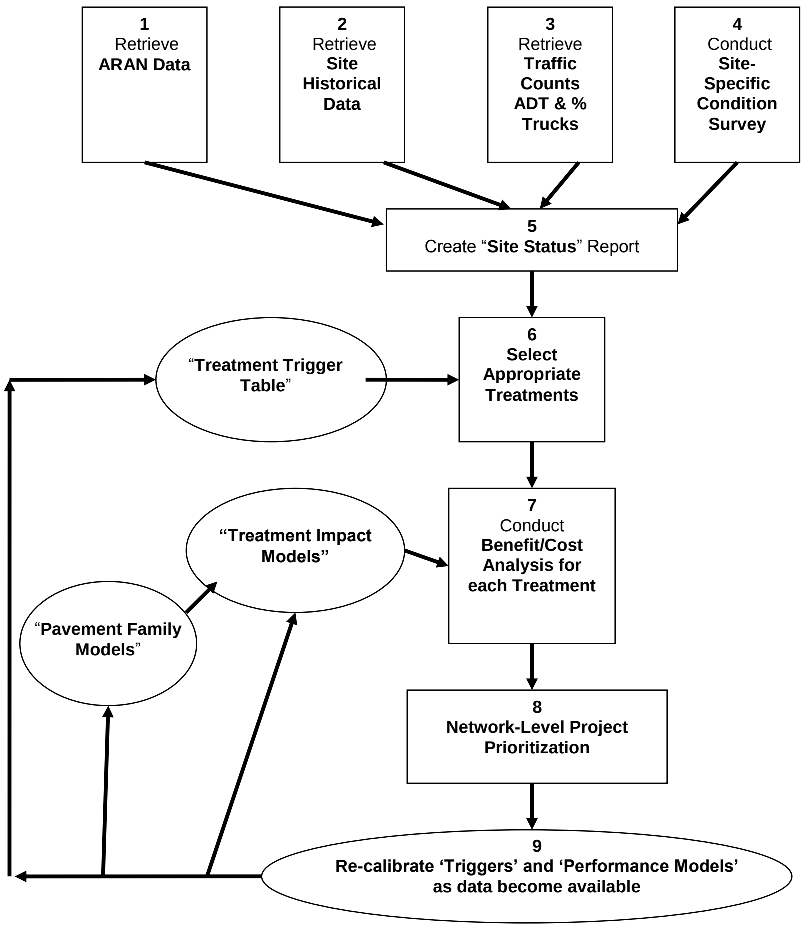


Fig. 1.1 – Procedural steps for implementing a modified pavement management process (Zimmerman et al. 2011).

A more complete discussion is included in the following steps. The treatment selection process can be used in both programming and for actual project-specific selection. Of course, nothing can replace experience. Data retrieval (Steps 1-3) is presented in detail in Volume II of this study.

Step 1**-**Make an assessment of the functional and structural performance of the existing pavement by retrieval of archived data:

- Annual road condition (ARAN) survey data (overall condition [PASER rating and IRI], including trends. IRI and overall condition are not necessarily indicators of specific forms of distress but can be useful as preliminary identifiers of candidate treatments. *[Data comes from ARAN Viewer and ARAN Inventory surveys, and SS Pavement]*
- Any specific distress types including severity and extent *[ARAN Viewer]*
- If safety is a specific issue: (friction numbers and crash data)
- If noise is a specific issue (pavement-tire noise data)

Step 2- ***Retrieve site historical data***:

- Functional classification: *[from ARAN Inventory and SS Pavement]*
- Urban or rural, geographic location, traffic access, posted speed limit, pavement family type, age, design life, cross-sectional design, construction records, maintenance and rehabilitation information: materials and thicknesses, drainage features: *[Data from a variety of sources such as the Pavement Tool, Sharepoint, District maintenance spreadsheets, STIP, J-Drive, ragmaps, asphalt summary sheets, historic state highway maps, concrete 2-AA sheets, archived project plan sheets (Z-Drive), and as-builts on ProjectWise and CDs and microfilm]*
- Subgrade soil: *[Data from Table 7.18 (more detail can be found from the websites of ASU and USDA, MoDOT Soils & Geology section records, and concrete 2-AA sheets, as discussed in Volume II)]*
- Weather: *[DT32, DP01, FT data from Table 7.18 (more detail can be found from NOAA website and AASHTOWare)]*

Table 7.18 – Subgrade and climate data

		Climate Data					Soils Data					
County	Travelway	DP01	DT32	AFI(50)	F/T	Geologic Areas	P200	PI	LL	GI	Pclay	PSwell
Boone	MO 124	70.5	105.2	939	66.8	GlacPlains	91	28	52	28	40	6.8
Boone	RT E	69.0	101.8	897	64.6	GlacPlains	64	29	52	16	42	7.6
Boone	RT N	68.3	102.1	873	66.4	GlacPlains	96	18	36	18	25	1.8
Boone	RT HH	69.7	103.4	908	65.9	GlacPlains	84	27	48	22	40	6.2
Butler	US 67	70.1	92.3	372	67.0	SE Lowlands	53	5	17	0	20	0.1
Callaway	RT F	71.0	111.0	928	67.1	GlacPlains	91	28	52	28	40	6.8
Callaway	RT C	71.6	111.7	888	72.0	GlacPlains	91	28	52	28	40	6.8
Callaway	RT B	70.2	112.7	967	66.3	GlacPlains	84	27	50	24	41	6.3
Callaway	RT D	67.3	111.4	864	68.3	GlacPlains	68	25	45	15	41	5.2
Camden	MO 7	63.5	89.1	576	60.1	Ozarks	46	17	40	4	37	1.9
Camden	RT J	63.6	89.3	553	57.9	Ozarks	53	22	45	10	45	4.1
Cole	RT C	69.5	100.6	770	74.4	Ozarks	74	25	49	19	47	5.7
Cole	RT E	69.6	99.3	759	73.0	Ozarks	61	30	53	16	45	8.7
Cooper	MO 135	68.0	106.2	877	61.6	GlacPlains	98	25	46	27	36	4.8
Cooper	RT J	67.8	103.7	798	55.3	GlacPlains	98	25	46	27	36	4.8
Cooper	RT M	68.1	106.9	857	64.4	GlacPlains	90	16	34	17	23	1.3
Cooper	MO 87	68.8	107.1	866	62.9	GlacPlains	96	18	36	18	25	1.8
Crawford	RT M	72.6	101.7	593	66.6	Ozarks	18	6	20	0	12	0.1
Dent	MO 32	72.3	92.0	538	62.4	Ozarks	28	16	40	0	33	1.5
Dent	RT K	67.9	94.0	527	61.1	Ozarks	28	16	40	0	33	1.5
Gasconade	MO 28	73.3	110.8	685	66.0	Ozarks	62	29	53	16	32	6.5
Gasconade	MO 19	73.2	112.3	664	68.5	Ozarks	51	28	50	11	42	7.0
Gasconade	RT Y	72.8	111.8	702	67.4	Ozarks	49	25	47	9	40	5.1
Grundy	MO 6	66.1	128.3	1210	69.3	GlacPlains	72	22	34	14	34	3.4
Grundy	US 65	65.4	127.7	1290	69.6	GlacPlains	65	20	36	10	31	2.6
Howard	MO 240	69.2	105.8	882	64.9	GlacPlains	95	30	50	31	32	7.0
Howard	MO 3	69.6	108.3	886	65.0	GlacPlains	71	28	47	18	40	6.8
Howard	MO 87	69.3	110.2	903	64.9	GlacPlains	82	21	41	17	33	3.0
Laclede	MO 32	65.4	92.3	554	57.8	Ozarks	47	0	0	6	39	0.0
Laclede	MO 64	64.2	90.2	574	58.8	Ozarks	44	22	44	8	44	4.0
Laclede	RT J	68.0	91.3	572	59.6	Ozarks	66	20	46	12	45	3.2
Lawrence	MO 174	69.8	92.5	622	60.4	WestPlains	45	21	43	6	38	3.2
Miller	MO 17	66.6	94.1	695	62.9	Ozarks	60	28	50	15	55	8.5
Moniteau	MO 5	66.0	99.5	752	63.3	Ozarks	62	29	53	16	45	8.0
Monroe	US 24	69.5	103.9	1030	65.8	GlacPlains	91	28	52	28	40	6.8
Morgan	MO 52	65.2	97.1	682	59.4	Ozarks	62	29	53	16	45	8.0
Morgan	RT W	65.2	97.4	725	58.5	Ozarks	63	33	56	20	49	11.6
Osage	RT T	72.5	100.8	736	65.9	Ozarks	61	30	53	16	45	8.7
Osage	MO 133	71.5	99.6	734	69.5	Ozarks	61	30	53	16	45	8.7
Pettis	US 50	66.9	105.3	904	53.3	GlacPlains	98	25	46	24	36	4.8
Phelps	RT BB	74.3	98.3	611	69.3	Ozarks	34	17	35	6	27	1.6
Phelps	RT F	73.5	96.5	585	67.6	Ozarks	18	6	20	0	12	0.1
Phelps	US 63	74.7	97.2	652	66.1	Ozarks	61	30	53	16	45	8.7
Phelps	US 63	75.0	104.3	675	66.1	Ozarks	42	13	33	6	28	0.9
Pulaski	RT T	68.6	92.8	536	58.8	Ozarks	53	22	45	10	46	4.1
Pulaski	MO 17	69.0	93.5	583	61.3	Ozarks	66	20	46	12	45	3.2
Pulaski	MO 133	69.5	93.6	576	61.5	Ozarks	66	20	46	12	45	3.2
Schuyler	US 63	66.2	118.2	1265	78.1	GlacPlains	95	32	55	34	40	9.4
St. Francois	MO 8	71.0	101.7	627	65.9	St.Francis	92	13	35	12	30	0.9
St. Francois	MO 32	70.6	101.0	603	67.0	St.Francis	92	13	35	12	30	0.9
Washington	MO 21	69.9	102.1	563	69.6	Ozarks	35	18	39	1	33	2.1
Washington	MO 47	68.8	101.3	649	65.0	Ozarks	34	23	45	2	38	4.1
Washington	MO 185	70.9	109.2	629	68.9	Ozarks	35	18	39	1	33	2.1

Step 3- ***Retrieve traffic information***: Annual Average Daily Traffic (AADT); percentage trucks or Annual Average Daily Truck Traffic (AADTT)(Commercial Truck Volume): *[Data from ARAN Viewer, SS-Pavement, and TR 50 reports]*

Step 4- As necessary, ***conduct various site-specific condition surveys***:

- Visual survey to obtain distress type, severity, and extent:
  - Environmental (thermal) cracking
  - Raveling
  - Bleeding
  - Polishing
  - Longitudinal cold joint cracking
  - Joint reflective cracks
  - Longitudinal edge breakup
  - Stable rutting
  - Structural rutting
  - Corrugations/shoving
  - Depressions/bumps
  - Potholes
  - Substandard Patches
- Drainage survey: minimum of a visual survey:
  - Presence of moisture-related distress
  - Cut/fill depth
  - Transverse slopes (pavement and shoulder)
  - Ditch geometrics (depth, width, longitudinal slope)
  - Drainage effectiveness
- Coring, non-destructive evaluation *[Construction & Materials databases, J-Drive, and ProjectWise]*
- Friction numbers, noise data

Step 5- Combine information from steps 1 through 4 into a "Site Status Report".

Step 6- ***Decide whether the project is a candidate for Preservation or Rehabilitation***, e.g. are the pavement's distresses primarily treatable by preservation methods and there is no excessive distress associated with structural or subsurface materials problems? Fig. 7.9 and Tables 7.1 and 7.2 can be used to decide whether a certain type of distress is appropriate for Preservation or for Rehabilitation; Fig. 7.9 requires IRI and PASER input, while Tables 7.1 and 7.2 require individual distress type, severity, and extent. For instance, such distresses as settlement, heaving/swelling, severe longitudinal wheel path cracking, structural rutting, mix instability rutting, delaminations, corner breaks, and subsurface drainage are not listed as candidates for Preservation remediation; rather, these are more appropriately dealt with by Rehabilitation methods. Another clue that a Rehabilitation should be done rather than Preservation is if the rate of IRI change is greater than about 7-8 in./mile per year, the deterioration is likely due to structural or subsurface material issues. Finally, is there a history of pavement problems in this location? Has the pavement passed beyond the “Good” condition? Affirmative answers would steer the designer into considering rehabilitation.

Fig. 7.9 – IRI vs. time with recommended treatment and rehabilitation types for asphalt surfaced roadways and associated PASER values.

Table 7.1 – Matching treatment type to distress type for asphalt-surfaced pavements (Peshkin et al. 2011b)

Treatment	PCI/ PCR	Ravel/ Weather			Bleed	Polish	Cracking L = Low M = Medium H = High														
							Fatigue[b]/ Long WP[c]/ Slippage			Block			Trans Thermal[c]			Joint Reflect			Long/ Edge[d]		
		L	M	H			L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Crack filling	75-90									x									X		
Crack sealing	80-95									X			X	X		X	X				
Profile milling	80-90		x	x	x																
Slurry sealing	70-85	x	x	x		x	x			x	x		x			x			x		
Micro-surfacing	70-85	x	x	x		x	x			x	x		x	x		x			x		
Chip seal, single	70-85	x	x	x		x	x			x	x		x	x		x	x		x	x	
Chip seal, double	70-85		x	x		x	x			x	x	x	x	x	x			x	x	x	x
UBAWS	65-85	x	x	x		x	x			x	x		x	x		x	x		x	x	
Thin overlay	60-80	x	x	x		x	x	x		x	x	x	x	x	x	x	x	x	x	x	x
Mill & overlay	60-75		x	x			x	x			x	x	x	x	x	x	x	x		x	x
Hot in-place recycling[a]	70-85		x	x			x	x		x	x			x	x		x	x	x	x	
Cold in-place recycling	60-75						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ultrathin White-topping	60-80					x		x	x		x	x		x	x		x	x		x	x
Fog seal							x														
Scrub seal							x														

[a] Surface recycle/HMA overlay
[b] Fatigue(alligator) cracking: L= < ¼” width or <10% area; M= ¼-½“or 10-20%; H = ½” or 20-30%
[c] Longitudinal Wheel Path and Transverse cracking: L= < ¼” width; M= ¼-½“; H = ½” width
[d] Edge cracking: L = no material loss; M = 0-10% loss; H = >10% loss
[e] “X” = highly or generally recommended

Table 7.1 – Matching treatment type to distress type for asphalt-surfaced pavements (Peshkin et al. 2011b), cont'd.

Treatment	PCI/ PCR	Ride	Friction	Noise	Deformation L = Low M = Medium H = High											
					Wear/ Stable Rutting			Corrug/ Shove			Bumps/ Sags			Patches		
					L	M	H	L	M	H	L	M	H	L	M	H
Crack filling	75-90															
Crack sealing	80-95															
Profile milling	80-90	x			x	x					x	x		x	x	
Slurry sealing	70-85		x	x										x		
Micro-surfacing	70-85		x	x	x									x		
Chip seal, Single	70-85		x		x									x	x	
Chip seal, double	70-85	x	x		x	x		x			x			x	x	x
UBAWS	65-85	x	x	x	x			x			x			x	x	
Thin overlay	60-80	x	x	x	x	x	x	x	x		x	x		x	x	x
Mill & overlay	60-75	x	x		x	x	x	x	x	x	x	x	x	x	x	x
Hot in-place recycling[a]	70-85	x	x		x	x	x	x	x		x	x		x	x	
Cold in-place recycling	60-75	x	x		x	x	x	x	x	x		x	x		x	x
Ultrathin White-topping	60-80	x				x	x		x	x					x	x
Fog seal																
Scrub seal																

Table 7.2 – Matching treatment type to distress type for concrete-surfaced pavements (Peshkin et al. 2011b)

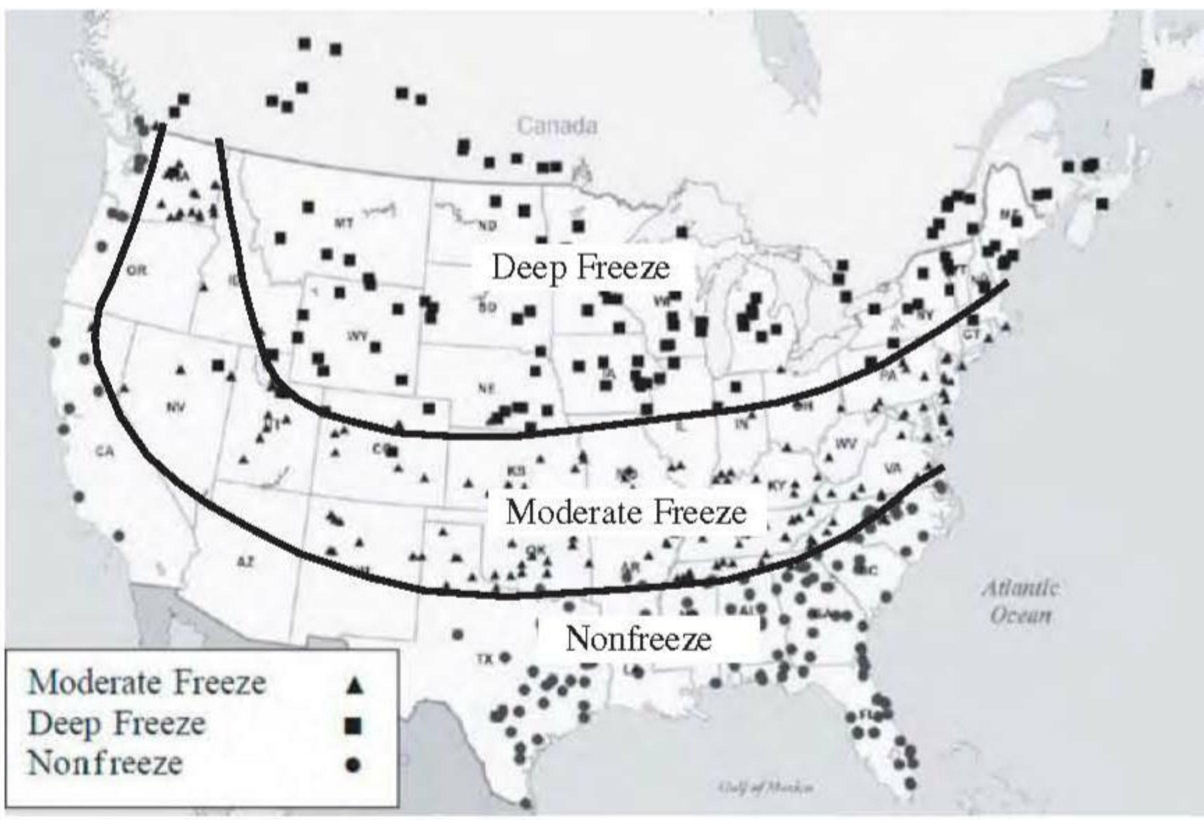
Treatment	PCI/ PCR	D-Cracking			Surface Distress		Joint Distress L=Low M=Medium H=High						Cracking Distress L =Low M= Medium H = High						Map Crack/ Scale
		L = Low M = Med H = High			Polish	Pop-outs	Joint Seal Damage			Joint Spall			Corner Cracks			Long/ Trans Cracks			
		L	M	H			L	M	H	L	M	H	L	M	H	L	M	H	
Joint resealing	75-90							x	x										
Crack sealing	70-90												x	x		x	x		
Diamond grinding	70-90				x														X
Diamond grooving	70-90																		
UBAWS	70-90	x			x												X		X
Thin overlay	70-90	x			x												x		x
Partial depth patching	65-85					x				x	x	x						x	
Full-depth patching	65-85		x	x					x				x	x	x				
Dowel-bar retrofit	65-85																		

Table 7.2 – Matching treatment type to distress type for concrete-surfaced pavements (Peshkin et al. 2011b), cont'd.

Treatment	PCI/ PCR	Ride	Friction	Noise	Deformation L= Low M= Medium H = High					
					Faulting			Patches		
					L	M	H	L	M	H
Joint resealing	75-90									
Crack sealing	70-90									
Diamond grinding	70-90	x	x	x	x	x	x	x	x	x
Diamond grooving	70-90		x	x						
UBAWS	70-90	x	x	x	x			x	x	x
Thin OL	70-90	x	x	x	x			x	x	x
Partial depth patching	65-85								x	
Full-depth patching	65-85	x					x		x	x
Dowel-bar retrofit	65-85					x	x			

In order to select the proper treatments and then narrow them down to one or two, the *performance needs* of the project would be evaluated next:

1) The project's targeted performance goals (e.g. improve smoothness only, improve structural condition or enhance structural capacity, improve friction, reduce noise, or improve surface drainage (splash/spray, cross slope))
2) Available funding for alternate treatment times of intervention
3) Traffic level/functional roadway classification
4) Match of the proposed treatment types with the distress type, severity and extent [see below discussion]
5) Appropriate match of treatment to climate (in Deep Freeze zone? [Fig. 7.5])



Source: Adapted from Jackson and Puccinelli 2006.

Fig. 7.5 – Climate zones in the US (Peshkin et al. 2011a).

6) DOT experience with a given treatment (extent and success)

7) DOT practice or district preference (includes maintenance considerations, e.g. behavior during snowplowing)

8) Motorist preferences (e.g. HMA vs. surface treatment)

Construction constraints would also need to be considered:

9) Time of year construction (weather limitations)

10) Geometrics (curves, intersections, curb-and-gutter, etc.)

11) Work zone duration restrictions, e.g. facility downtime: one day, weekend, longer

12) Traffic disruption/control and safety

13) Availability of qualified contractors

14) Availability of good quality materials for a given treatment

15) Availability of specialized equipment and/or materials

16) Environmental considerations (e.g. air quality, recycling/sustainability)

Once it is established that Preservation (as opposed to Rehabilitation) is appropriate, and the performance needs and constraints are determined, with the Site Status Report in hand, Tables 7.22a and 7.22b trigger tables can be used as a guide for ***selection of candidate treatments*** appropriate for certain IRI and PASER ratings for HMA pavements as deemed by MoDOT policy. The treatment categories are not specific beyond “Surface Treatments” and “Thin Overlays”. The tables are used to match general treatment type with level of condition in terms of overall condition (PASER). Determination of specific treatments is presented next.

Table 7.22a – MoDOT Pavement Preservation Treatment Triggers combined from EPG and Direction for asphalt minor roads with greater than 400 AADT, with estimated PASER ratings. PASER rating of 4 but IRI <170 is not shown

Condition (PASER)				**IRI <140**				**IRI 140-170**		
				8	7	6	5	7	6	5
Environmental Cracks (≥5)	**LS**	**Surface Wear**	**L (6-7)**	DN	CT	CT & ST		CT	CT & ST	
			M (6)	DN		CT & ST			CT & ST	
			H (5)	DN		CT & TOL	CT & TOL		CT & TOL	CT & TOL
	MS		**L (6-7)**	DN	CT&ST	CT & ST		CT & ST	CT & ST	
			M (6)	DN		CT & ST			CT & ST	
			H (5)	DN		TOL	TOL		TOL	TOL
	HS		**L (6-7)**	DN	TOL	TOL		TOL	TOL	
			M (6)	DN		TOL			TOL	
			H (5)	DN		TOL	TOL		TOL	TOL

LS = Low Severity; MS = Moderate Severity; HS = High Severity
L = Low; M = Moderate; H = High
DN = Do Nothing; CT = Crack Treatment; ST = Surface Treatment; TOL = Thin Overlay

Table 7.22b – MoDOT Pavement Preservation Treatment Triggers for asphalt minor roads with less than 400 AADT, with estimated PASER ratings

Condition (PASER)				IRI <170				IRI 170-220		
				8	7	6	5	7	6	5
Environmental Cracks (≥5)	LS	Surface Wear	L (6-7)	DN	CT	CT & ST		CT	CT & ST	
			M (6)	DN		CT & ST			CT & ST	
			H (5)	DN		CT & ST	CT & ST		CT & TOL	CT & ST
	MS		L (6-7)	DN	CT&ST	CT & ST		CT & ST	CT & ST	
			M (6)	DN		CT & ST			CT & ST	
			H (5)	DN		CT & ST	CT & ST		CT & ST	ST
	HS		L (6-7)	DN	CT&ST	CT* & ST		ST	ST	
			M (6)	DN		CT* & ST			ST	
			H (5)	DN		CT* & ST	CT* & ST		ST	ST

LS = Low Severity; MS = Moderate Severity; HS = High Severity
L = Low; M = Moderate; H = High
DN = Do Nothing; CT = Crack Treatment; ST = Surface Treatment
*At high levels of cracking may not be candidates for crack treatment

After a visual survey has been conducted and individual distress levels of extent and severity are determined, one would enter Table 7.1 and ***select several alternate treatments*** appropriate for *each of the distresses individually* for the assigned pavement family. Table 7.2 is the PCC counterpart to Table 7.1. Both of these tables show windows of opportunity in terms of overall condition. From this analysis, a shorter list of *just the treatment types appropriate for all the significant distresses* would be made.

Peshkin et al. recommend to further narrow the list of climate-compatible treatments: areas in the "Deep Freeze" climate zone, such as the northern tier of counties in Missouri. Not recommended are slurry seals, diamond grooving, thin overlays on PCC, and UBAWS on PCC (urban areas). Of course, local experience would take precedence over generic recommendations.

Peshkin et al. also note that concrete treatments such as ultra-thin whitetopping (UTW), partial- and full-depth patching, and dowel bar retrofitting have work zone duration restrictions in that these normally take longer than overnight/single-shift.

Step 7- With the appropriate service lives and relative costs per lane mile, **conduct an Equivalent Cost (EAC) analysis, a Benefit/Cost (B/C), or a Remaining Service Life (RSL) effectiveness analysis** for each potential treatment. Items #13 and #14 above should be considered. Poor quality materials and construction practices could reduce the expected service lives of the TOL and the chip seal (which are calculated from Eq. 7.4 and 7.6, respectively), which will increase the EAC result.

Service lives of all alternative treatments must be determined. Service lives of 1-in. overlays, chip seals, and 3¾-in. overlays on composite pavements can be predicted from Eqs. 7.4, 7.6, and 7.8, as shown in Table A1. Guidance for input for the equations is in Table 7.17. Calculated lives should be adjusted downward for expected poor quality aggregate or construction (e.g. unfavorable time of year, workforce inexperience, minimal inspection, etc.). One way to accomplish this is by using a conservative (high) value for IRI_o (such as much greater than 86 for 1-in. overlays and much greater than 119 for chip seals).

Table A.1 – IRI prediction equations

Equation No.	Equation
7.1 Full-Depth Family	$\ln[IRI] = 3.2047+0.0082896*IRI_o+0.042714*SA+0.0009721*IRI_t+0.0046686*FT+ 0.044608*\ln[Pclay]-0.086607*LstTrtThk$
7.2 PCC Family	$IRI = -737.6002 + 1.53927*SA + 7.4635*DP01 + 2.3945*DT32 + 0.64656*P200$
7.3 Composite Family	$\ln[IRI] = 3.6259 + 0.0053057*IRI_t + 0.059198*SA - 0.36468*IRI_{improv}+ 0.0053319*DT32$
7.4 1-in. Overlay	$SA = (\ln[IRI_T]-3.2547-0.0065029*IRI_0-0.0013964*IRI_t-0.0034073*FT- 0.055036*\ln[Pclay])/0.039867$
7.6 Chip Seals	$SA = [49.0979 - 0.85358*IRI_0 - 0.16403*IRI_t - 0.75390*FT + IRI_T]/2.8642$
7.8 3¾-in. Overlay	$SA = [\ln(IRI_T) - 2.4382 - 0.016750*IRI_0 + 0.44938*\ln(IRI_{improv}) - 0.0097153*DT32)]/0.065681$

This can also be done by assuming a value for service life, based on experience supplemented by information from Table 7.7 and discussion in Sub-items 7.3.3.1.a-d, f, and g.

Table 7.7 – Expected performance of preservation treatments (Wu et al. 2010; Peshkin et al. 2011b; ILDOT 2009)

Treatment	Distress Triggers	Treatment Life (yrs) [Peshkin et al.]	Performance Period (yrs) [ILDOT]	Pavement Life Extension (yrs)	
				[Wu et al.]	[Peshkin et al.]
Asphalt-Surfaced					
Crack filling		2-4	2-4		NA
Crack sealing	Cracking (various)	3-8	2-8	0-4	2-5
Slurry seal	Ride, cracking (various)	3-5*	3-6	4-7	4-5
Micro-surfacing: Single course Double course	Cracking (various), shallow rutting	 3-6** 4-7	4-7	 3-8	 3-5 4-6
Chip seal:	Cracking (various), raveling				
Single course		3-7	4-6	3-8	5-6
Double course		5-10***	5-7		8-10
Triple course			6-8		
UBAWS		7-12	7-12		NA
Thin overlay	Ride, cracking (various), rutting, raveling	5-12****	7-10	3-23	NA
Mill & thin overlay	Ride, cracking (various), rutting	5-12	7-10	4-20	NA
Hot in-place recycling, thin overlay	Cracking (various), rutting	6-10	6-15	3-8	NA
Cold in-place recycling, thin overlay	Cracking (various), rutting	6-15	5-13	4-17	NA
Profile milling		2-5	0		NA
Fog sealing	Cracking patching		1-3	4-5	
Sand seal			3-4		
Cape seal			4-7		
¾” overlay + chip			5-7		

seal					
Whitetopping	Ride, cracking (various)			3-17	
Concrete-Surfaced					
Joint resealing	Ride; open joints	2-8	4-8 (Hot pour asphalt) 8 (Silicone)	4	5-6
Crack sealing		4-7	4-8		NA
Diamond grinding	Ride, faulting	8-15	8-15	4-17	NA
Diamond grooving		10-15	0		NA
Partial depth patching	Cracked panels, joint spalling	5-15	5-15	1-7	NA
Full depth patching	Ride, cracked panels	5-15	10-15	3-14	NA
Dowel bar retrofitting	Ride, cracked panels with some faulting and transverse joint spalling	10-15	10-15	2-16	NA
UBAWS		6-10	7-12		NA
Thin HMA overlay	Ride, faulting, cracked panels	6-10		1-20	NA

*4.8, **7.4, *** 7.3, **** 8.4 Watson and Heitzman (2014)

Generic unit costs can be obtained from Tables 7.9, 7.19, and 7.23, but it would be much preferable to use more current and representative cost information available to MoDOT from the Pavement Tool, Sharepoint, and district maintenance spreadsheets, among other sources. If desired, LCCA can be used to calculate various treatments' overall costs for a programmed (analysis) period in terms of a summed present day cost. EAC is then calculated as the unit cost divided by the service life.

Table 7.23 – Equivalent Annual Costs for various treatments

Treatment	Unit Cost Range ($)	Unit Cost Average ($/yd^3)	Perf Life Range (yrs)	Perf Life Average (yrs)	EAC ($/yd^3/yr)
Asphalt-Surfaced					
Crack filling	0.10-1.20/ft	N/A	2-4	N/A	N/A
Crack sealing	0.75-1.50/ft	N/A	2-8	N/A	N/A
Slurry sealing	0.75-1.00/yd^3	0.88	3-6	4.5	0.20
Micro-surfacing (single-course)	1.50-3.00/yd^3	2.25	4-7	5.5	0.41

Chip seal Single course	1.50-2.00/yd^3	1.75	4-6 5-7 6-8	5.0*	0.35
Chip seal Double course	N/A	2.62**	N/A	10.0**	0.26**
UBAWS	4.00-6.00/ yd^3	5.00	7-12	9.5	0.53
Thin overlay	4.00-6.00/ yd^3	5.00	7-10	8.5*	0.59
Mill & thin overlay	5.00-10.00/ yd^3	7.50	7-10	8.5	0.88
Hot in-place recycling (excluding overlay)	2.00-7.00/ yd^3	4.50	6-15	10.5	0.43
Cold in-place recycling (excluding overlay)	1.25-3.00/ yd^3	2.12	5-13	9.0	0.24
Profile milling	0.35-0.75/ yd^3	0.55	0	N/A	N/A

Concrete-Surfaced					
Joint resealing	1.00-2.50/ft	N/A	4-8 (Hot pour asphalt) 8 (Silicone)	N/A	N/A
Crack sealing	0.75-2.00/ft	N/A	4-8	N/A	N/A
Diamond grinding	1.75-5.50/ yd^3	3.62	8-15	11.5	0.31
Diamond grooving	1.25-3.00/ yd^3	2.12	0	N/A	N/A
Partial depth patching	75.00-150.00/ yd^3 (patched area; equivalent 2.25-4.50/ yd^3 based on 3% surface area patched)	3.38	5-15	10	0.34
Full depth patching	75.00-150.00/ yd^3 (patched area; equivalent 2.25-4.50/ yd^3 based	3.38	10-15	12.5	0.27

	on 3% surface area patched)				
Dowel bar retrofitting	25.00-35.00/bar (equivalent 3.75-5.25/ yd^3, based on 6 bars per 12-ft crack/joint and crack/joint retrofits every 30 ft)	4.50	10-15	12.5	0.36
UBAWS	4.00-6.00/ yd^3	5.00	7-12	8.0	0.62
Thin overlay	3.00-6.00/ yd^3	4.50	6-10	8.0*	0.56

*Data from this report shows for MoDOT roadways, chip seals average 6 years and thin overlays and modest structural overlays average 12-13 years

** Double chip seals estimated 1.5 cost and 2 times life of single chip seals

Benefit-cost analyses can also be conducted by calculating the areas under various specific route or family curves and treatment deterioration curves. Specific route performance curves are preferred, but do not exist at present. Therefore, family curves will have to be used. These can be calculated via Eqs. 7.1, 7.2, and 7.3 from Table A1. The treatment performance curves that exist at present are calculated from Eqs. 7.4, 7.5, and 7.8, also in Table A1. Other treatment type performance curves should be developed by MoDOT as experience with them is gained. The "benefit" is the net added area under the treatment curve, which does not include the area under the do-nothing part of the existing pavement curve. Decisions have to be made as to calculation of treatment lives, which involve choices about beginning and terminal target IRI or PASER thresholds, which are arbitrary. Table 7.17 and Fig. 7.9 offer advice on IRI_o and IRI_T; IRI_t can be obtained from ARAN and SS Pavement.

The RSL method could also be employed by comparing RSL_{BT}s, which come from the performance curves.

Table 7.17 – Input for family and treatment models

Required Information	Equation	Sources
IRI_o after treatment applied	7.1 for Full-Depth 7.3 for Composites 7.4 for 1-in. overlays 7.6 for chip seals 7.8 for 3¾-in. overlays	Experience with similar pavement condition-contractor-materials; if no experience available, use 55 for extremely smooth, 86 for average conditions, 126 for less than ideal smoothness (1-in. overlays); 17, 119, and 126 (chip seals); 39, 56, and 70 for 3¾-in. overlays on PCC
IRI_T target IRI threshold	all	Typical choices: 135, 140, 150, 170
IRI_t before treatment applied	7.1 for Full-Depth 7.3 for Composites 7.4 for 1-in. overlays 7.6 for chip seals 7.8 for 3¾-in. overlays	ARAN Inventory tables and SS Pavement
DT32	7.2 for Concrete 7.3 for Composites 7.8 for 3¾-in. overlays	Table 7.18; Fig. 3.26 from Task 1 report; NCDC website
DP01	7.2 for Concrete	Table 7.18; Fig. 3.25 from Task 1 report; NCDC website
FT	7.1 for Full-Depth 7.4 for 1-in. overlays 7.6 for chip seals	Table 7.18; AASHTOWare
P200	7.2 for Concrete	Testing of samples from the project site; MoDOT Soils & Geology section records; ASU website or USDA website (see Task 1 report for use of these websites and data); Table 7.18
Pclay	7.1 for Full-Depth 7.4 for 1-in. overlays	Testing of samples from the project site; MoDOT Soils & Geology section records; ASU website or USDA website (see Task 1 report for use of these websites and data); Table7.18
LastTrtThk	7.1 for Full-Depth	ARAN Inventory tables and SS Pavement

Step 8- Using the calculated cost effectiveness of all treatments and all projects, ***create a network-level (county, region or state-wide) project prioritization list***. Project prioritization could be based on other considerations in addition to cost effectiveness.