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Final Report 518

Development of Cost Effective Treatment Performance and Treatment Selection Models

by

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16. Abstract
Louisiana Department of Transportation and Development (DOTD) has spent substantial financial resources on various rehabilitation and maintenance treatments to minimize pavement distresses and improve pavement life. Such treatments include, but are not limited to, chipseal, crack seal, micro-surfacing, thin and thick overlays, and structural overlays. Unfortunately, DOTD has not conducted a full scale performance assessment and cost-effectiveness analysis of all the aforementioned treatments. A recent study completed by the Louisiana Transportation Research Center (LTRC) regarding the pavement management system (PMS) and performance modeling emphasized the importance of developing treatment performance and selection models. In this regards, the LTRC initiated a three-phase research study that addresses such needs by developing rigorous treatment performance and selection models that are specific to the mission and management strategies of DOTD. The following are the three phases.

- Phase I- Review and Project Selection
- Phase II- Performance Modeling and Costs and Benefits of Treatments
- Phase III- Model Integration and Training

This final report focuses on the results of Phase I and Phase II of the study. Phase I is related to review of district pavement treatment practices and project selection for the development of pavement treatment performance models. Phase II deals with the performance modeling and costs and benefits of treatments. The data obtained from the Phase I was used to develop cost-effective pavement treatment performance and treatment selection models during Phase II of this study. Trigger values for optimum timing of pavement treatments and an approach to use the performance models cost effectively were established. All these findings will be integrated in the software development and training for DOTD staff to be completed during Phase III of this study.

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LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

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ABSTRACT

The Louisiana Department of Transportation and Development (DOTD) has spent substantial financial resources on various rehabilitation and maintenance treatments to minimize pavement distresses and improve pavement life. Such treatments include, but are not limited to, chipseal, crack seal, micro-surfacing, thin and thick overlays, and structural overlays. Unfortunately, DOTD has not conducted a full-scale performance assessment and cost-effectiveness analysis of all the aforementioned treatments. A recent study completed by LTRC regarding the pavement management system (PMS) and performance modeling emphasized the importance of developing treatment performance and selection models. In this regards, the LTRC initiated a three-phase research study that addresses such needs by developing rigorous treatment performance and selection models that are specific to the mission and management strategies of DOTD. The following are the three phases.

- Phase I- Review and Project Selection
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This final report focuses on the results of Phase I and Phase II of the study. Phase I was related to review of district pavement treatment practices and project selection for the development of pavement treatment performance models. Phase II was related to performance modeling and costs and benefits of treatments. The data obtained from the Phase I was used to develop cost-effective pavement treatment performance and treatment selection models during Phase II of this study. Trigger values for optimum timing of pavement treatments and an approach to use the performance models cost effectively were established. All these findings will be integrated in the software development and training for DOTD staff to be completed during Phase III of this study.

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Furthermore, the investigators extend their thanks to the University of Louisiana at Lafayette for providing the means and resources to conduct this research. Last but not least, the time and effort put by Mr. Bhuyan and Mr. Nur, graduate research assistants, and Ms. Bodin and Mr. Fadhil, undergraduate assistants for data mining, data analysis, model development and report writing, and organizing are highly appreciated.

IMPLEMENTATION STATEMENT

During Phase I of the study, review and evaluation of the existing district practices and procedures regarding treatment selection and project scoping were conducted. During Phase II, the DOTD database was searched to identify pavement projects that received various treatment types and have adequate time dependent pavement performance data. The data were used to develop before and after treatment performance models. Based on the time dependent pavement performance data before and after treatment, the treatment benefits were calculated. The results were used to calibrate the trigger values for various distresses and treatment types. Further, guidelines and methodologies for treatment cost benefit analyses were developed. Based on the results, various implementable recommendations were made and submitted for approval by DOTD. It should be noted that Phase III of the study deals with the overall implementation of the findings and recommendations.

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INTRODUCTION

Since the bulk of the highway systems in Louisiana have been constructed and completed, emphasis has shifted from design and construction to pavement preservation. Unfortunately, the engineering knowledge and the types of experience required to preserve the highway systems are much different than those required to originally design and construct them. Hence, the experience gained in the initial phase of construction, however important, cannot be solely used to preserve the systems. In general, the term “system pavement preservation” includes preventive (or preservation) and corrective maintenance, rehabilitation, and reconstruction activities. Maintenance activities are typically applied at the initial stage of pavement deterioration. Rehabilitation activities, on the other hand, are applied at later stages. The cost-effectiveness of any pavement preservation program depends on the selection of the optimum time of intervention; project boundaries and pavement fix type.

The Louisiana Department of Transportation and Development (DOTD) manages approximately 18,000 roadway miles consisting of flexible pavements (ASP), jointed concrete pavements (JCP), composite pavements (COM), and continuously reinforced concrete (CRC) pavements. The road network is deteriorating over time due to increasing traffic volume, axle loads, environmental factors, and aging. Timely rehabilitation and preservation of pavement systems are imperative to maximize their benefits in terms of driver’s comfort and safety, and spending of tax payers’ dollars. DOTD has spent substantial financial resources on various rehabilitation and maintenance treatments to minimize pavement distresses and improve pavement life. Such treatments include, but are not limited to, chipseal, crack seal, micro-surfacing, thin and thick overlays, rubblize and overlay, and structural overlays. Unfortunately, DOTD has not conducted a full scale performance assessment and cost-effectiveness analysis of all the aforementioned treatments. A recent study completed by LTRC regarding the pavement management system (PMS) and performance modeling emphasized the importance of developing treatment performance and selection models. LTRC initiated a three-phase research study that addresses such needs by developing rigorous treatment performance and selection models that are specific to the mission and management strategies of DOTD. The three phases are:

- Phase I- Review and Project Selection
- Phase II- Performance Modeling and Costs and Benefits of Treatments
- Phase III- Model Integration and Training

This report focuses on the results of Phase I and II of the study, which is related to the review of district pavement treatment practices, project selection, development of pavement treatment performance models, and development of pavement treatment selection models.

OBJECTIVE

The objectives for Phase I and II of the study are as follows:

- Conduct a comprehensive review of the DOTD state-of-the-practice regarding pavement projects and treatment selection procedures. The review will be based on the analysis of the results of surveys (questionnaire).
- Identify the pavement treatments and treatment projects with sufficient historical records (e.g., traffic, age, pavement structure and materials, cost data, etc.) and pavement performance data by utilizing the information stored in DOTD databases.
- Develop performance models for various treatments and pavement type
- Update trigger and reset values for various distresses and treatment types.
- Propose guidelines and recommendations cost-effective pavement treatment selection in the state of Louisiana.

SCOPE

The scope of the Phase I of the study is as follows:

- Study the state-of-the-practice of all DOTD districts regarding the processes or the steps used in the evaluation of deteriorated pavement sections and the selection of candidate projects and their boundaries for treatments.
- Establish matrices based on the information obtained from all districts. The matrices include information regarding:
    - The types of pavement distresses, their extent, and severity levels prior to the application of the treatment
    - The estimated remaining service life (RSL) of the pavement section before treatment and the estimated service life of the treatment
    - The types of pre-treatment repairs applied to the deteriorated pavement projects
    - The pavement age, pavement class, pavement materials types, layer thicknesses, and traffic volumes.
    - Construction practices
- Identify and select pavement projects based on the information included in the matrices with all the good historic record of performance, age, treatments, traffic thickness, materials, and others related information.
- For each of the projects identified in the previous step, obtain the following information from various districts and PMS section of DOTD:
    - The cost of all treatments, including the cost of pre-treatment actions and excluding the cost of other types of work such as shoulder, guard rail, and other safety improvements.
    - The historical records regarding the types and costs of routine and heavy maintenance and preservation actions (data from MATTS, TOPS, LETS, etc.).
    - All available time series pavement distress data prior to and after the application of the treatment. These include the remaining service life (RSL) of the pavement sections prior to treatment and the estimated service life of the treatment.

The scope of the Phase II of the study is as follows:

- Analyze the performance of all pavement sections prior and after treatment using the PMS distress data.
- Compare the costs and performance of pavement sections with and without treatments and their life extension based on the treatment.
- Evaluate the pavement treatment selection models along with associated trigger and reset values of indices for various treatment actions.
- Conduct regression analysis to develop pavement treatment models for each pavement type

and distress type.

- Update pavement treatment selection models based on performance data and the experience gained over time.
- Based on the type and causes of pavement distresses in the state of Louisiana, analyze and recommend a process for identifying the optimal timing for the application of rehabilitation actions and/or preventive maintenance treatments.
- Develop guidelines for the implementation of cost-effective pavement preservation strategies that would maximize the user and agency benefits and minimize their costs.

DOTD STATE-OF-THE-PRACTICE

Introduction

The measured and collected pavement condition and distress data are typically subjected to various analyses and/or evaluation to accomplish various objectives including:

1. Assessment of the condition or the health of the pavement network.
2. Selection of pavement projects to be subjected to preservation or rehabilitation actions.
3. Determination, for each potential pavement project, of the optimum time and types of the pavement preservation and rehabilitation actions.
4. Estimation of the benefits of pavement preservation and rehabilitation actions.

The analyses and evaluation of the pavement condition and distress data are typically based on:

1. A descriptive scale, such as very good, good, fair, poor, and very poor. The descriptive term is typically based on the last measured pavement condition and distress data and their severities and extents, and on road classification. The descriptive terms could also be based on the pavement distress index scale as shown in Figure 1 *[1]*.

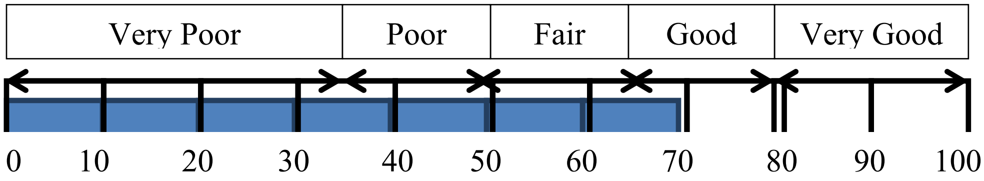


Figure 1
Descriptive pavement condition scale based on the pavement distress index

2. A distress index or distress indices based on a continuous rating scale such as zero to ten or zero to hundred; zero indicates "failed" pavement and one hundred implies pavement in excellent condition (such as a new pavement), as shown in Figure 1. The distress index could be calculated using one distress type such as transverse cracks, longitudinal cracks, and so forth or a combination of various distress (composite pavement index). In this method, deduct points are typically assigned based on the magnitude, severity, and extent of the measured pavement condition and distress. Along the rating scale or the distress index scale, various trigger values could be established to trigger various types of pavement actions. For example, one trigger value indicates crack sealing, another reflects thin overlay,

and still another trigger value may initiate heavy pavement rehabilitation and so forth. Conceptual trigger values are illustrated in Figure 2. Finally, the trigger values are generally functions of the pavement condition or distress type and the highway classification *[1]*.

3. The measured time series pavement condition and distress data coupled with threshold values for each distress and condition type, are used to calculate the remaining service life (RSL) of the various pavement sections along the pavement network or the weighted average RSL of the entire network. The calculation of the RSL could be based on the measured time series pavement condition and distress data directly and the established threshold values or on the calculated time dependent distress indices and the assigned trigger values. In this method, the measured time series pavement condition and distress data are modeled using the proper mathematical function (exponential function for IRI, power function for rut depth, and logistic S-shaped curve for cracking). The calculation of RSL is illustrated in Figure 3.

As a part of Phase I of this study a comprehensive literature review was also conducted to summarize the findings of previous research in relation to the pavement treatment performance, type, and time of treatment, treatment life, and performance models. The summary of the literature search is reported in Appendix B.

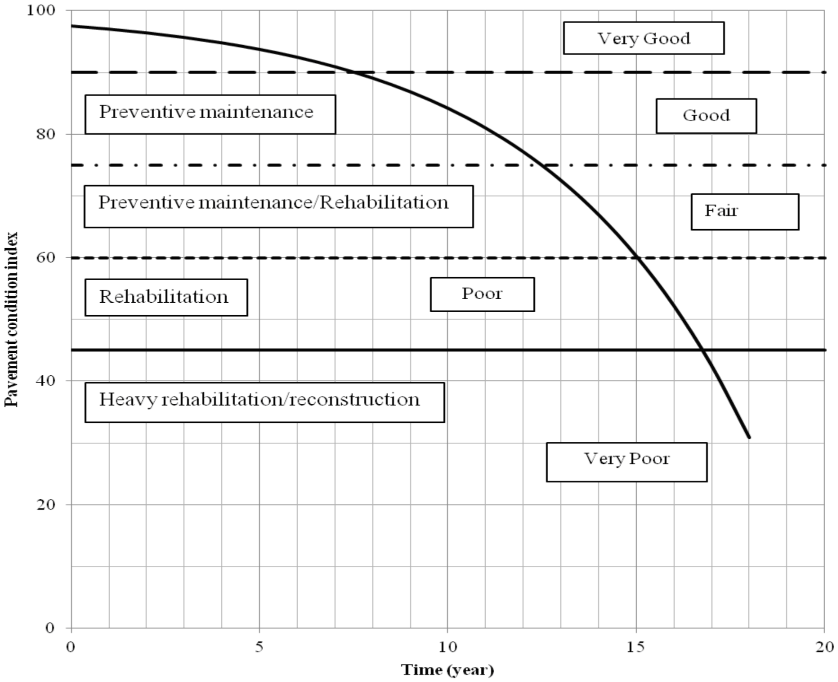


Figure 2
Illustration of the pavement condition index and descriptive scale

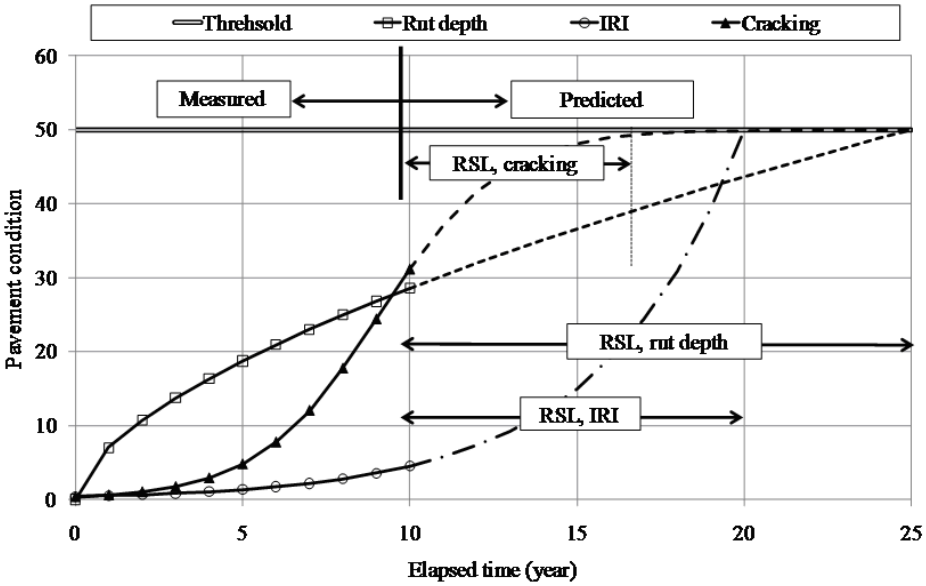


Figure 3
Illustration of the remaining service life based on IRI, rut depth, and cracking

DOTD State-of-the-Practice

The pavement management system (PMS) state-of-the-practice of the Louisiana Department of Transportation and Development (DOTD) includes:

- Pre-established deduct points based on each pavement surface distress type, its severity level and extent, and on the pavement surface condition such as IRI and rut depth.
- Distress indices based on the deduct points.
- Trigger values to flag pavement projects and possible treatment type.
- Reset values representing pavement condition right after treatment

For all pavement distresses, the pre-established deduct points are listed in Table 1 through Table 7 and shown in Figure 4 through Figure 10. The deduct points are functions of the type of the pavement surface distress, its associated severity level, and its extent.

The deduct points for pavement surface conditions (roughness and rut depths) and the associated roughness and rut indices are listed Table 8 and shown in Figure 11 and Figure 12. The deduct points and indices for roughness and rut depths listed in Table 8 could also be obtained using equations (1) through (4).

For $0 < \text{IRI} \leq 50$ inch/mile deduct point =0.0

For IRI $\geq$ 50 inch/mile Deduct Points = 0.2(IRI) – 10 (1)

Roughness Index = -0.2(IRI) + 110 (2)

For $0 < \text{rut} \leq 0.125$ in. Deduct Points = 0.0

For rut $\geq$ 0.125 in. Deduct Points = 80(rut depth) -10 (3)

Rut Index = -80(rut depth) + 110 (4)

For each pavement distress and condition type, the deduct points are used to calculate pavement condition or distress index. All indices are based on a scale from zero to one hundred, with one hundred as the upper range of very good or excellent pavement conditions, whereas, Table 9 provides a list of ranges of the distress indices that defines the various descriptive pavement conditions as a function of highway classification. Table 10 to Table 13 provides lists of the DOTD distress index based trigger values for various pavement, distress, and treatment types and for three road classes: Interstate, Arterial, and collectors. The listed trigger values were established by the DOTD in May 2006. The trigger values are used to determine the needed type of treatment. When a pavement project treatment is accomplished, the index value is reset to the reset index values listed in Table 14 to Table 17.

Table 1
DOTD deduct points for alligator cracking in flexible pavement

Deduct points for alligator cracking (flexible pavements)						
Severity level	Extent (square ft.)					
	0-51	51-701	701-1301	1301-2401	2401-3168	3168-9999.99
Low	0	1-16	16-21	21-25	25-28	28
Med	0	1-21	21-29	29-36	36-49	49
High	0	1-29	29-43	43-50	50-61	61

Table 2
DOTD deduct points for random cracking in flexible pavements

Deduct points for random cracking (flexible pavements)						
Severity level	Extent (linear ft.)					
	0-31	31-301	301-1601	1601-5001	5001-6001	6001-9999.99
Low	0	1-3	3-16	16-18	18-20	20
Med	0	1-16	16-21	21-30	30	30
High	0	1-26	26-28	28-42	42-48	48

Table 3
DOTD deduct points for patching in flexible and composite pavements

Deduct points for patching (flexible and composite pavements)							
Severity level	Extent (square ft.)						
	0-31	31-81	81-151	151-251	251-501	501-6336	6336-9999.99
Low	0	1-2	2-21	21-23	23-27	27-30	30
Med	0	1-4	4-23	23-27	27-31	31-41	41
High	0	1-11	11-27	27-30	30-47	47-65	65

Table 4
DOTD deduct points for random cracking in composite pavements (COM)

Deduct points for random cracking (composite pavements)						
Severity level	Extent (linear ft.)					
	0-51	51-326	326-901	901-2001	2001-6001	6001-9999.99
Low	0	1-3	3-5	5-16	16-33	33
Med	0	1-16	16-26	26-35	35-46	46
High	0	1-32	32-40	40-55	55-70	70

Table 5
DOTD deduct points for transverse cracking in jointed concrete pavements (JCP)

Deduct points for transverse cracking (JCP)						
Severity level	Extent (linear ft.)					
	0-13	13-49	49-241	241-469	469-2900	2900-9999
Low	0	1-13	13-23	23-31	31-35	35
Med	0	1-16	16-41	41-49	49-61	61
High	0	1-20	20-46	46-63	63-77	77

Table 6
DOTD deduct points for longitudinal cracking for jointed and continuously reinforced **concrete pavements (JCP and CRC)**

Deduct points for longitudinal cracking (JCP and CRC)						
Severity level	Extent (linear ft.)					
	0-11	11-31	31-131	131-261	261-1000	1000-9999
Low	0	1-13	13-23	23-31	31-35	35
Med	0	1-16	16-41	16-49	49-61	61
High	0	1-20	20-46	46-63	63-70	70

Table 7
DOTD deduct points for patching in jointed and continuously reinforced concrete pavements (JCP and CRC)

Deduct points for patching (JCP and CRC)							
Severity level	Extent (square ft.)						
	0-31	31-81	81-151	151-251	251-501	501-6336	6336-9999.99
Low	0	1-2	2-6	6-12	12-15	15-20	20
Med	0	1-4	4-11	11-31	31-40	40-45	45
High	0	1-11	11-20	20-35	35-47	47-65	65

Table 8
DOTD deduct values roughness index as a function of the average International Roughness Index (IRI) and rut index as a function of the average rut depth.

Point Number	Roughness			Rut Depth		
	Average IRI (inch/mile)	Deduct Points	Ruff Index	Average Rut (in.)	Deduct Points	Rut Index
1	0	0	100	0	0	100
2	50	0	100	0.125	0	100
3	100	10	90	0.25	10	90
4	150	20	80	0.5	30	70
5	200	30	70	0.75	50	50
6	250	40	60	1	70	30
7	300	50	50	1.25	90	10
8	350	60	40	1.375	100	0
9	400	70	30			
10	450	80	20			
11	500	90	10			

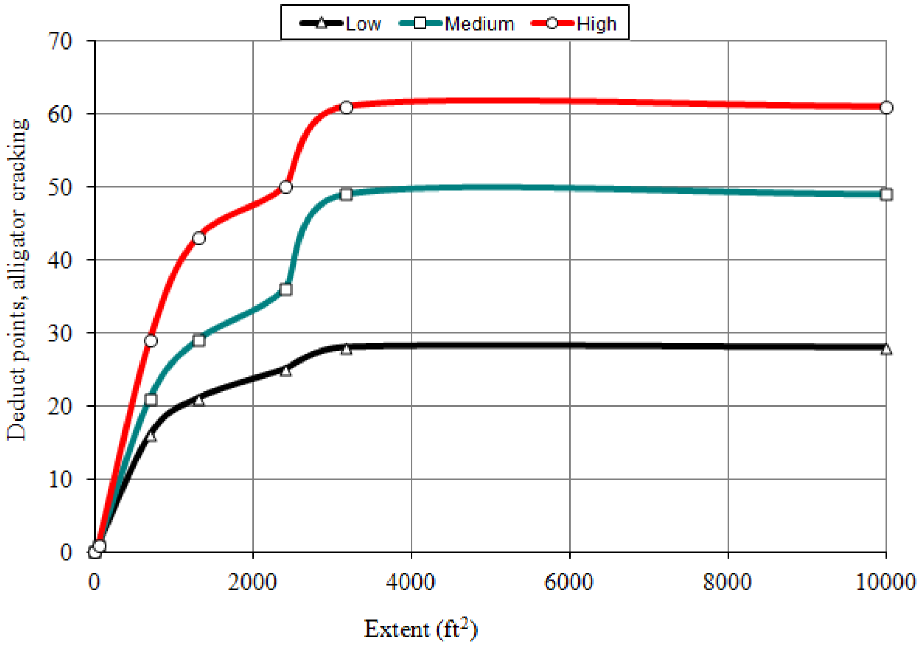


Figure 4
DOTD deduct points for alligator cracking, flexible pavements

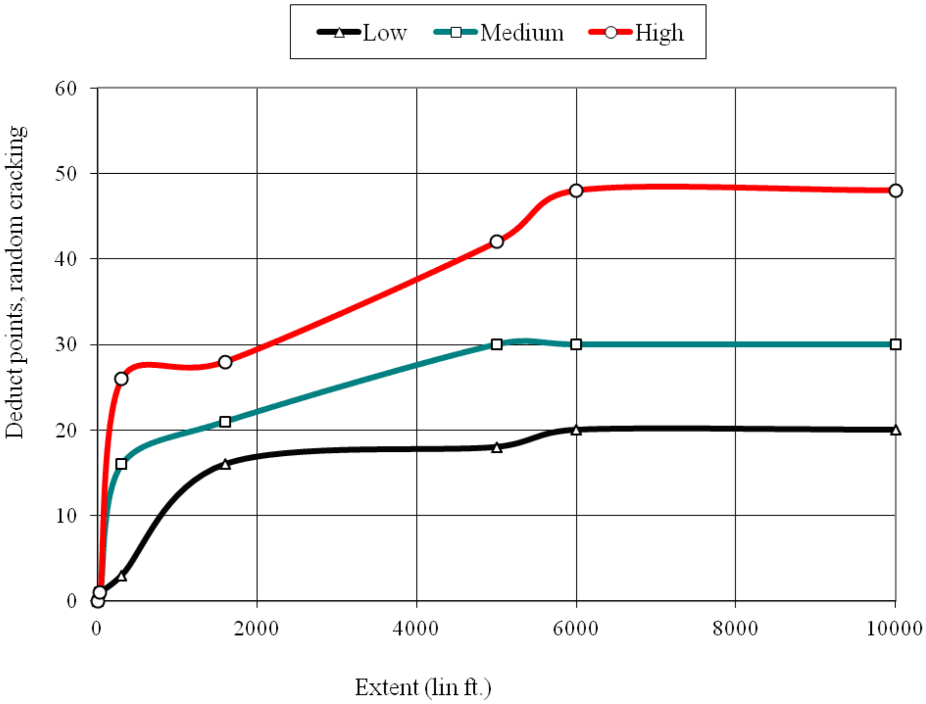


Figure 5
DOTD deduct points for random cracking, flexible pavements

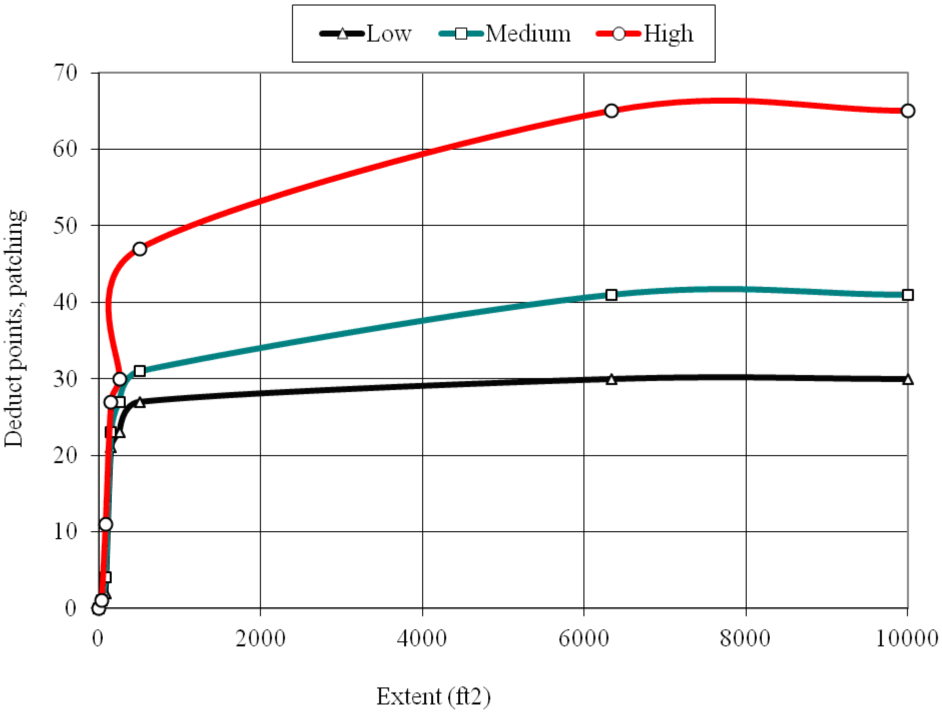


Figure 6
DOTD deduct points for patching, flexible and composite pavements

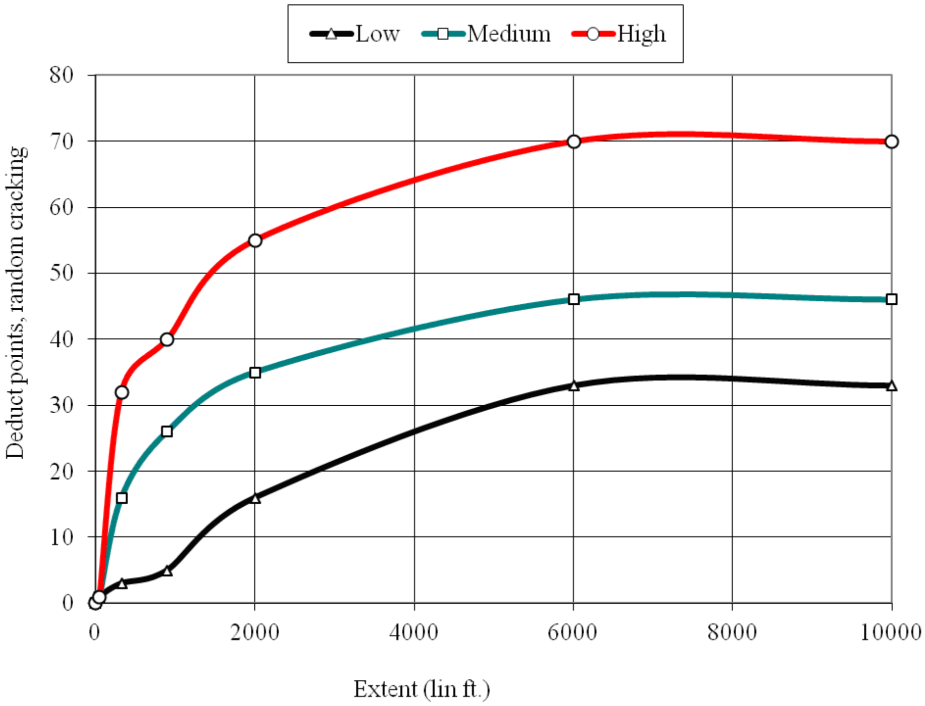


Figure 7
DOTD deduct points for random cracking, composite pavements

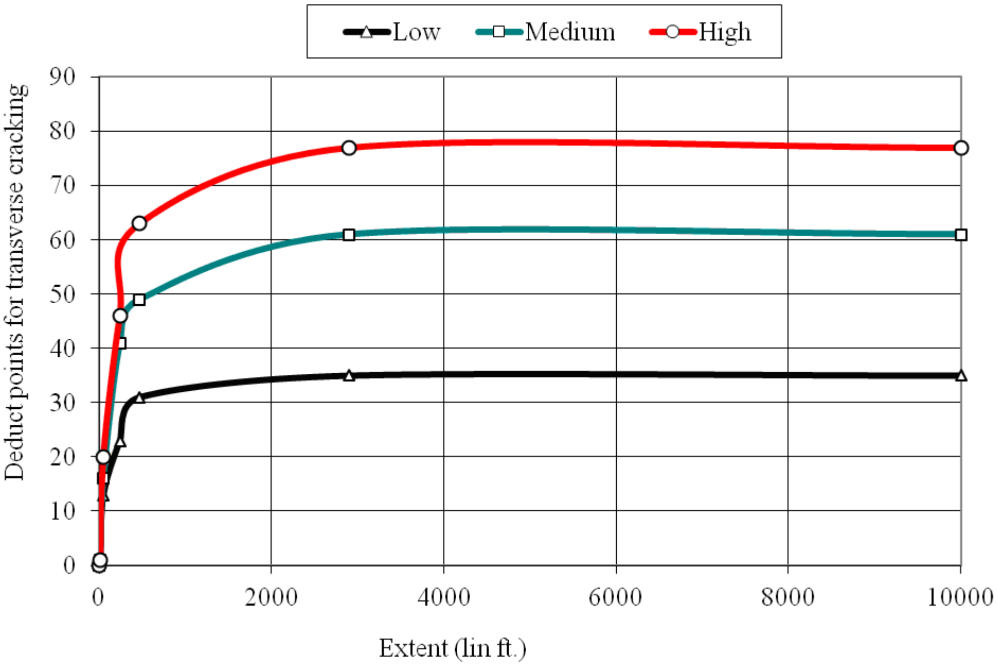


Figure 8

DOTD deduct points for transverse cracking, jointed concrete pavements

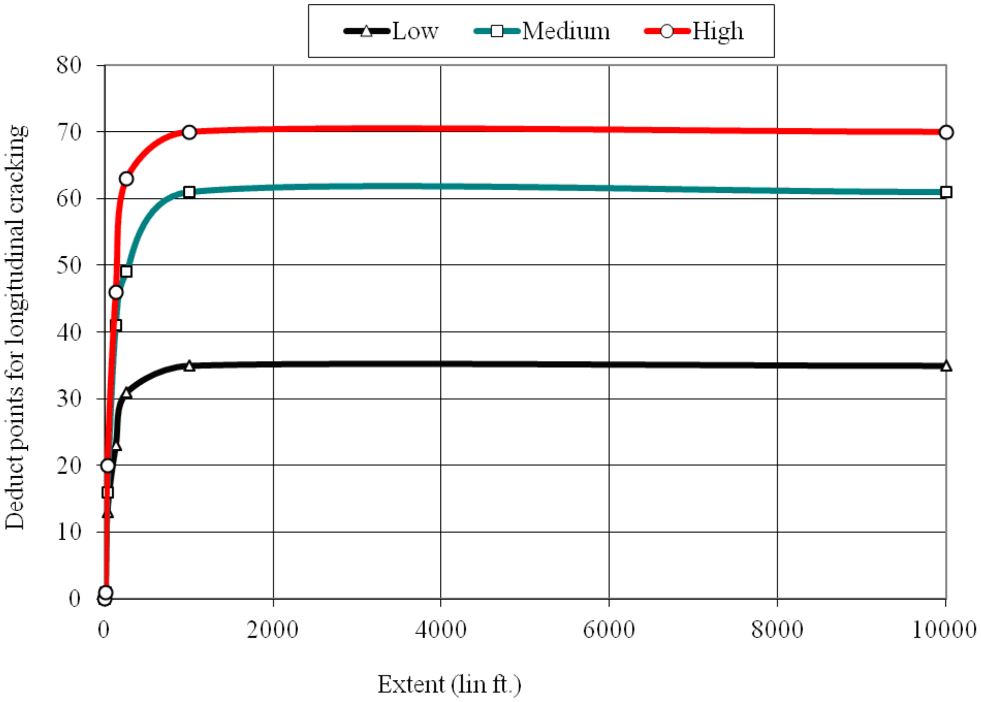


Figure 9

DOTD deduct points for longitudinal cracking, jointed and continuously reinforced concrete pavements (JCP and CRC)

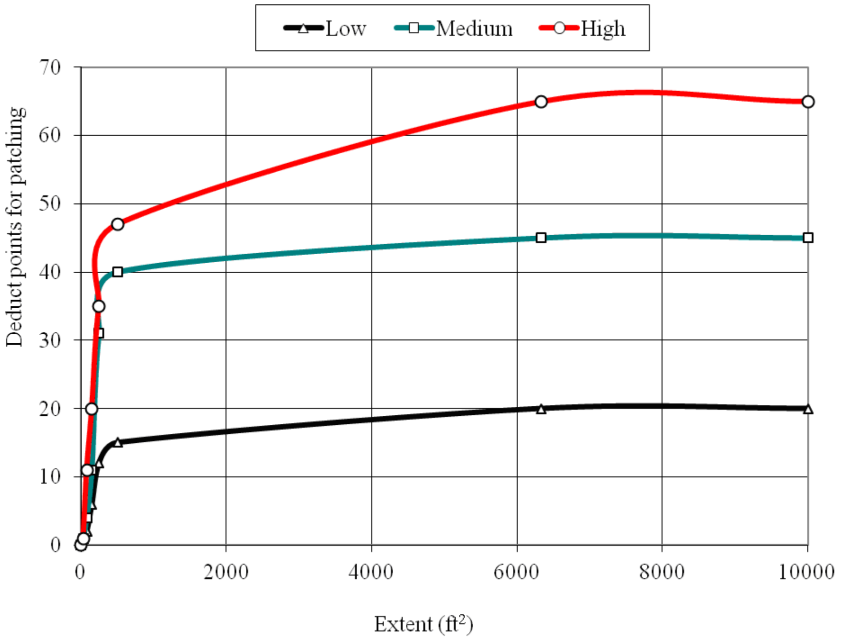


Figure 10

DOTD deduct points for patching in jointed and continuously reinforced concrete pavements (JCP and CRC)

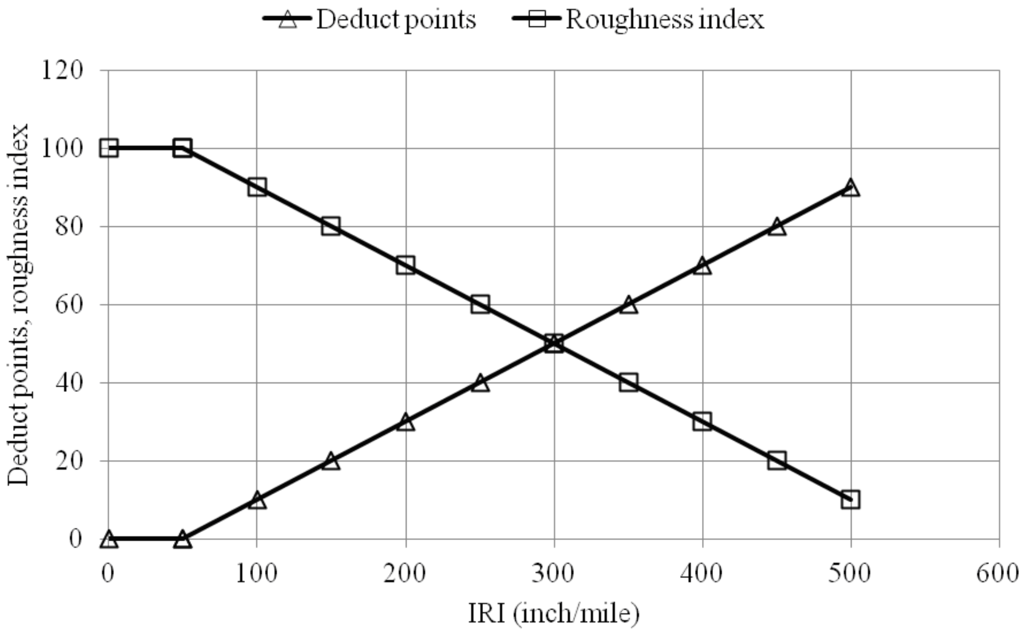


Figure 11

DOTD deduct points for roughness and roughness index

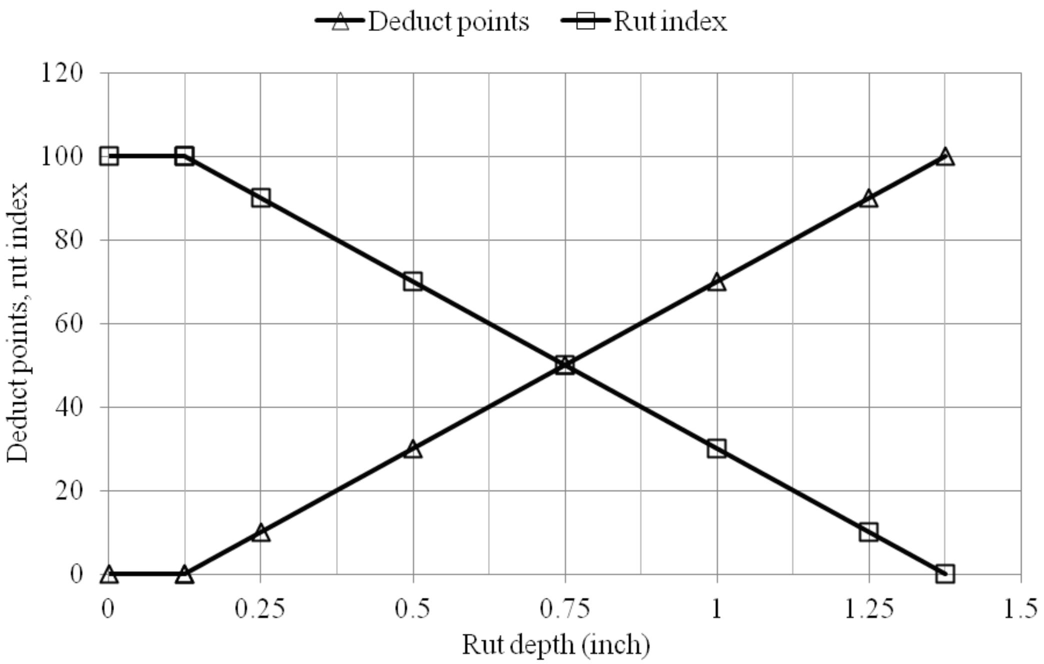


Figure 12
DOTD deduct points for rut depth and rut index

Table 9
Range of pavement performance indices for five descriptive conditions and three highway classification

Condition	Interstates	NHS	RHS & SHS
Very Good	100-96	100-95	100-95
Good	95-90	94-88	94-85
Fair	89-76	87-70	84-65
Poor	75-65	69-60	64-50
Very Poor	64-0	59-0	49-0

Table 10

Flexible pavements trigger values based on distress and condition indices for various road class and treatment type

#	DESCRIPTION	ALLIGATOR	RANDOM	PATCH	RUT	ROUGHNESS
1	Microsurfacing on Interstate	>=98	>=98	>=98	>=80<90	>=85
2	Thin Overlay on Interstate (Cold Plane 2", put 2" back; 0-100 sq.yds. Patching)	>=90	>=85	>=90	<80	>=85 <90
3	Medium Overlay on Interstate (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-300 sq.yds Patching)	>=65 <90	<90	>=65 <90		<85
4	Structural Overlay on Interstate (7" Overlay; 700 sq.yds. Patching)	<65		<65		
5	Microsurfacing on Arterial	>=95	>=95	>=95	>=65 <90	>=80
6	Thin Overlay on Arterial (Cold Plane 2", put 2" back; 0-100 sq.yd. Patching)	>=80 <90	>=80 <95	>=80	<65	>=70 <90
7	Medium Overlay on Arterial (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-300 sq.yds Patching)	>=60 <80	<80	>=60 <80		<70
8	Structural Overlay on Arterial (5.5" Overlay; 700 sq.yds. Patching)	<60		<60		
9	Polymer Surface Treatment on Collector	>= 85	>=80 <95	>=80	>=65	>=80
10	Microsurfacing on Collector	>=95	>=95	>=95	>=65 <90	>=80
11	Thin Overlay on Collector (2" Overlay; 0-100 sq.yd. Patching)	>=75	>=70 <80	>=70	<65	>=65 <80
12	Medium Overlay on Collector (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-500 sq.yds Patching)	>=55 <75	<70	>=55 <70	<65	>=55 <65
13	In Place Stabilization on Collector (In-Place Stabilization & 3" A.C.)	<55		<55		<55

Table 11
Composite pavements trigger values based on distress and condition indices for various road class and treatment type

#	DESCRIPTION	RANDOM	PATCH	RUT	ROUGHNESS	NO_LANES
1	Microsurfacing on Interstate	>=95	>=98	>=80 <90	>=90	
2	Thin Overlay on Interstate (Cold Plane 2", put 2" back; 0-100 sq.yds. Patching)	>=90	>=90	<80	>=85 <90	
3	Medium Overlay on Interstate (Cold Plane 2", put 3.5" back & 1.5" on shoulders; 100-500 sq.yds Patching)	>=65 <90	>=65 <90		<85	
4	Structural Treatment on Interstate (CRCP Composites-Cold Plane 2", heavy patching (600 sq.yds), put 5.5" back &3.5" on shoulders) or (JCP Composites-Cold Plane to slab, Rubblize, put 7" A.C., 3" A.C. on shoulders)	<65	<65			
5	Microsurfacing on Arterial	>=95	>=95	>=65 <90	>=80	
6	Thin Overlay on Arterial (Curb & Gutter) (Cold Plane to slab, 300 sq.yds. Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	>=60 <95	>=60 <90	<65	<90	
7	Thin Overlay on Arterial (Non-Curb & Gutter) (Cold Plane 2", put 2" back, 100 sq.yds. Patching, 30 tons Joint Repair)	>=80 <95	>=80	<65	>=70 <90	
8	Medium Overlay on Arterial (Non-Curb & Gutter) Cold Plane to slab, put 3.5" Saw & Seal Back, 300 sq.yds. Concrete Patching, Clean & Reseal Joints or Cold Plane 2", 300 sq.yds. A.C. Patching, 30 tons Joint Repair, 3.5" Overlay)	>=50 <80	>=60 <80		<70	
9	Structural Overlay on Arterial (Curb & Gutter) (Cold Plane to slab, 1000 sq.yds. Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	<60	<60			
10	Structural Overlay on Arterial (Non-Curb & Gutter) Cold Plane 2", 600 sq.yds. A.C. Patching, 100 tons Joint Repair, 5.5" A.C. & 3.5" on Shoulders)	<50	<60			<=3
11	Rubblize and Overlay on Arterial (Non-Curb & Gutter) Cold Plane to Slab, Rubblize, 5.5" A.C. & 2" A.C. on Shoulders (4 or more lanes)	<50	<60			>=4
12	Microsurfacing on Collector	>=95	>=98	>=65 <90	>=80	
13	Thin Overlay on Collector (Curb & Gutter) (Cold Plane to slab, 300 sq.yds. Concrete Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	>=55 <90	>=55 <80	<65	<80	
14	Thin Overlay on Collector (Non-Curb & Gutter) (Cold Plane 2", put 2" back, 100 sq.yds. Patching, 30 tons Joint Repair)	>=70 <90	>=80	<65	>=65 <80	
15	Medium Overlay on Collector (Non-Curb & Gutter) Cold Plane to slab, put 3.5" Saw & Seal Back, 300 sq.yds. Concrete Patching, Clean & Reseal Joints or Cold Plane 2", 300 sq.yds. A.C. Patching, 30 tons Joint Repair, 3.5" Overlay)	>=50 <70	>=55 <80		<65	
16	Structural Overlay on Collector (Curb & Gutter) (Cold Plane to slab, 1000 sq.yds. Concrete Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	<55	<55			
17	Structural Overlay on Collector (Non-Curb & Gutter) Cold Plane 2", 600 sq.yds. A.C. Patching, 100 tons Joint Repair, 5.5" A.C. & 3.5" on Shoulders)	<50	<55			<=3
18	Rubblize and Overlay on Collector (Non-Curb & Gutter) Cold Plane to Slab, Rubblize, 5.5" A.C. & 2" A.C. on Shoulders (4 or more lanes)	<45	<55			>=4

Table 12
Jointed concrete pavements trigger values based on distress and condition indices for various road class and treatment type

#	DESCRIPTION	TRANS	LONG	PATCH	FAULTING	ROUGHNESS	NO_LANES
1	Seal Joints and Cracks on Interstate (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	>=80 <98	>=95 <98	>=90	<=0.2	>=85	
2	Minor Rehab on Interstate(Crack Sealing plus Clean & Reseal Joints, Partial Depth Patching, Grinding, Cross-Stitching, Slab Jacking, Full Depth Patching (**Not Greater Than:** 400 sq.yds.))	>=80	>=80 <95	>=80 <90	<.5	>=70 <85	
3	Major Rehab on Interstate(Curb & Gutter) (Minor Rehab. Plus up to 1000 sq.yds. Full Depth Patching)	>=40 <80	>=50 <80	>=50 <80	>=.5	>=60 <70	
4	Major Rehab on Interstate(Non-curb & Gutter) (Minor Rehab. Plus up to 1000 sq.yds. Full Depth Patching)	>=65 <80	>=65 <80	>=65 <80	>=.5	>=70	
5	Rubblize and Overlay on Interstate (Non-curb & Gutter)(Rubblize + 7" Overlay)	<65	<65	<65		<70	
6	Reconstruct on Interstate(Curb & Gutter)	<40	<50	<50		<60	
7	Seal Joints and Cracks on Arterial (Curb & Gutter) (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	>=80 <98	>=95 <98	>=90	<=0.2	>=85	
8	Seal Joints and Cracks on Arterial (Non-curb & Gutter) (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	>=80 <98	>=95 <98	>=90	<=0.2	>=85	
9	Minor Rehab on Arterial (Curb & Gutter) (Crack Sealing plus Clean & Reseal Joints, Partial Depth Patching, Grinding, Cross-Stitching, Slab Jacking, Full Depth Patching (**Not Greater Than:** 400 sq.yds.))	>=60 <80	>=60 <95	>=70 <90		>=60 <85	
10	Minor Rehab on Arterial (Non-curb & Gutter) (Crack Sealing plus Clean & Reseal Joints, Partial Depth Patching, Grinding, Cross-Stitching, Slab Jacking, Full Depth Patching (**Not Greater Than:** 400 sq.yds.))	>=60 <80	>=60 <95	>=70 <90		>=60 <85	
11	Major Rehab on Arterial (Curb & Gutter) (Minor Rehab. plus up to 800 sq.yds. Full Depth Patching plus 2" Saw & Seal Overlay)	<60	<60	<70	>=.5	<60	
12	Major Rehab on Arterial (Non-curb & Gutter) (Minor Rehab. plus up to 800 sq.yds. Full Depth Patching plus 3.5" Saw & Seal Overlay)	<60	<60	<70	>=.5	<60	<=3
13	Major Rehab on Arterial (Non-curb & Gutter) (Minor Rehab. plus up to 800 sq.yds. Full Depth Patching plus 3.5" Saw & Seal Overlay)	>=50 <60	>=50 <60	>=60 <70	>=.5	<60	>=4
14	Rubblize and Overlay on Arterial (Non-curb & Gutter) (Rubblize + 5" Overlay)	<50	<50	<60			>=4
15	Seal Joints and Cracks on Collector (Curb & Gutter) (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	>=75 <98	>=90 <98	>=90	<=0.2	>=80	
16	Seal Joints and Cracks on Collector (Non-curb & Gutter) (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	>=75 <98	>=90 <98	>=90	<=0.2	>=80	
17	Minor Rehab on Collector (Curb & Gutter) (Crack Sealing plus Clean & Reseal Joints, Partial Depth Patching, Grinding, Cross-Stitching, Slab Jacking, Full Depth Patching (**Not Greater Than:** 400 sq.yds.))	>=60 <75	>=60 <90	>=65 <90		>=60 <80	
18	Minor Rehab on Collector (Non-curb & Gutter) (Crack Sealing plus Clean & Reseal Joints, Partial Depth Patching, Grinding, Cross-Stitching, Slab Jacking, Full Depth Patching (**Not Greater Than:** 400 sq.yds.))	>=55 <75	>=55 <90	>=60 <90		>=55 <80	
19	Major Rehab on Collector (Curb & Gutter) (Minor Rehab. Plus up to 800 sq.yds. Full Depth Patching plus 2" Saw & Seal Overlay)	<55	<55	<60	>=.5	<55	
20	Major Rehab on Collector (Non-curb & Gutter) (Minor Rehab. Plus up to 800 sq.yds. Full Depth Patching plus 3.5" Saw & Seal Overlay)	<55	<55	<60	>=.5	<55	<=3

21	Major Rehab on Collector (Non-curb & Gutter) (Minor Rehab. Plus up to 800 sq.yds. Full Depth Patching plus 3.5" Saw & Seal Overlay)	>=45 <55	>=45 <55	>=55 <65	>=.5	<55	>=4
22	Rubblize and Overlay on Collector (Non-curb & Gutter) (Rubblize + 5” Overlay)	<45	<45	<55			>=4

Table 13

Continuously reinforced concrete pavements trigger values based on distress and condition indices for various road class and treatment type

#	DESCRIPTION	LONG	PATCH	ROUGHNESS
1	Minor Rehab on Interstate (Not Greater Than: 200 sq.yds. of Full Depth Patching & 4” A.C. Overlay)	>=65 <85	>=70 <85	<76
2	Major Rehab on Interstate (Not Greater Than: 400 sq.yds. of Full Depth Patching & 8” A.C. Overlay or Bonded Concrete Overlay)	>=50 <65	>=50 <70	
3	Reconstruction or Unbonded Concrete Overlay on Interstate	<50	<50	
4	Minor Rehab on Other (Not Greater Than: 200 sq.yds. of Full Depth Patching & 4” A.C. Overlay)	>=65 <85	>=70 <85	<75
5	Major Rehab on Other (Not Greater Than: 400 sq.yds. of Full Depth Patching & 8” A.C. Overlay or Bonded Concrete Overlay)	>=50 <65	>=50 <70	
6	Reconstruction or Unbonded Concrete Overlay on Other	<50	<50	

Table 14
Flexible pavements distress indices reset values

#	*DESCRIPTION*	ALLIGATOR	RANDOM	PATCH	RUT	ROUGHNESS	AAGE
1	Microsurfacing on Interstate	A 100	A 100	A 100	A 100	A 100	N -1
2	Thin Overlay on Interstate (Cold Plane 2", put 2" back; 0-100 sq.yds. Patching)	A 100	A 100	A 100	A 100	A 100	A 0
3	Medium Overlay on Interstate (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-300 sq.yds Patching)	A 100	A 100	A 100	A 100	A 100	A 0
4	Structural Overlay on Interstate (7" Overlay; 700 sq.yds. Patching)	A 100	A 100	A 100	A 100	A 100	A 0
5	Microsurfacing on Arterial	A 100	A 100	A 100	A 100	A 100	N -1
6	Thin Overlay on Arterial (Cold Plane 2", put 2" back; 0-100 sq.yd. Patching)	A 100	A 100	A 100	A 100	A 100	A 0
7	Medium Overlay on Arterial (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-300 sq.yds Patching)	A 100	A 100	A 100	A 100	A 100	A 0
8	Structural Overlay on Arterial (5.5" Overlay; 700 sq.yds. Patching)	A 100	A 100	A 100	A 100	A 100	A 0
9	Polymer Surface Treatment on Collector *	A 100	A 100	A 100	R 5	R 10	N -1
10	Microsurfacing on Collector	A 100	A 100	A 100	A 100	A 100	N -1
11	Thin Overlay on Collector (2" Overlay; 0-100 sq.yd. Patching)	A 100	A 100	A 100	A 100	A 100	A 0
12	Medium Overlay on Collector (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-500 sq.yds Patching)	A 100	A 100	A 100	A 100	A 100	A 0
13	In Place Stabilization on Collector (In-Place Stabilization & 3" A.C.)	A 100	A 100	A 100	A 100	A 100	A 0

Table 15
Composite pavements distress indices reset values

#	DESCRIPTION	ALLIGATOR	RANDOM	PATCH	RUT	ROUGHNESS	AAGE	PAVETYPE
1	Microsurfacing on Interstate	A 100	A 100	A 100	A 100	A 100	N -1	
2	Thin Overlay on Interstate (Cold Plane 2", put 2" back; 0-100 sq.yds. Patching)	A 100	A 100	A 100	A 100	A 100	A 0	
3	Medium Overlay on Interstate (Cold Plane 2", put 3.5" back & 1.5" on shoulders; 100-500 sq.yds Patching)	A 100	A 100	A 100	A 100	A 100	A 0	
4	Structural Treatment on Interstate (CRCP Composites-Cold Plane 2", heavy patching (600 sq.yds), put 5.5" back &3.5" on shoulders) or (JCP Composites-Cold Plane to slab, Rubblize, put 7" A.C., 3" A.C. on shoulders)	A 100	A 100	A 100	A 100	A 100	A 0	(Rubblize & Overlay) ASP
5	Microsurfacing on Arterial	A 100	A 100	A 100	A 100	A 100	N -1	
6	Thin Overlay on Arterial (Curb & Gutter) (Cold Plane to slab, 300 sq.yds. Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	A 100	A 100	A 100	A 100	A 100	A 0	
7	Thin Overlay on Arterial (Non-Curb & Gutter) (Cold Plane 2", put 2" back, 100 sq.yds. Patching, 30 tons Joint Repair)	A 100	A 100	A 100	A 100	A 100	A 0	
8	Medium Overlay on Arterial (Non-Curb & Gutter) Cold Plane to slab, put 3.5" Saw & Seal Back, 300 sq.yds. Concrete Patching, Clean & Reseal Joints or Cold Plane 2", 300 sq.yds. A.C. Patching, 30 tons Joint Repair, 3.5" Overlay)	A 100	A 100	A 100	A 100	A 100	A 0	
9	Structural Overlay on Arterial (Curb & Gutter) (Cold Plane to slab, 1000 sq.yds. Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	A 100	A 100	A 100	A 100	A 100	A 0	
10	Structural Overlay on Arterial (Non-Curb & Gutter) Cold Plane 2", 600 sq.yds. A.C. Patching, 100 tons Joint Repair, 5.5" A.C. & 3.5" on Shoulders)	A 100	A 100	A 100	A 100	A 100	A 0	
11	Rubblize and Overlay on Arterial (Non-Curb & Gutter) Cold Plane to Slab, Rubblize, 5.5" A.C. & 2" A.C. on Shoulders (4 or more anes)	A 100	A 100	A 100	A 100	A 100	A 0	ASP
12	Microsurfacing on Collector	A 100	A 100	A 100	A 100	A 100	N -1	
13	Thin Overlay on Collector (Curb & Gutter) (Cold Plane to slab, 300 sq.yds. Concrete Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	A 100	A 100	A 100	A 100	A 100	A 0	
14	Thin Overlay on Collector (Non-Curb & Gutter) (Cold Plane 2", put 2" back, 100 sq.yds. Patching, 30 tons Joint Repair)	A 100	A 100	A 100	A 100	A 100	A 0	
15	Medium Overlay on Collector (Non-Curb & Gutter) Cold Plane to slab, put 3.5" Saw & Seal Back, 300 sq.yds. Concrete Patching, Clean & Reseal Joints or Cold Plane 2", 300 sq.yds. A.C. Patching, 30 tons Joint Repair, 3.5" Overlay)	A 100	A 100	A 100	A 100	A 100	A 0	
16	Structural Overlay on Collector (Curb & Gutter) (Cold Plane to slab, 1000 sq.yds. Concrete Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	A 100	A 100	A 100	A 100	A 100	A 0	
17	Structural Overlay on Collector (Non-Curb & Gutter) Cold Plane 2", 600 sq.yds. A.C. Patching, 100 tons Joint Repair, 5.5" A.C. & 3.5" on Shoulders)	A 100	A 100	A 100	A 100	A 100	A 0	
18	Rubblize and Overlay on Collector (Non-Curb & Gutter) Cold Plane to Slab, Rubblize, 5.5" A.C. & 2" A.C. on Shoulders (4 or more lanes)	A 100	A 100	A 100	A 100	A 100	A 0	ASP

Table 16
Jointed concrete pavements distress indices reset values

#	DESCRIPTION	TRANS	LONG	PATCH	FAULTING	ROUGHNESS	AAGE	PAVETYPE
1	Seal Joints and Cracks on Interstate (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	A 100	A 100	A 100	N –1	N –1	N -1	
2	Minor Rehab on Interstate (Crack Sealing plus Clean & Reseal Joints, Partial Depth Patching, Grinding, Cross-Stitching, Slab Jacking, Full Depth Patching (**Not Greater Than:** 400 sq.yds.))	A 100	A 100	A 100	<=0.2	A 92	N -1	
3	Major Rehab on Interstate(Curb & Gutter) (Minor Rehab. Plus up to 1000 sq.yds. Full Depth Patching)	A 100	A 100	A 100	<=0.2	A 92	A 0	
4	Major Rehab on Interstate(Non-curb & Gutter) (Minor Rehab. Plus up to 1000 sq.yds. Full Depth Patching)	A 100	A 100	A 100	<=0.2	A 92	A 0	
5	Rubblize and Overlay on Interstate (Non-curb & Gutter) (Rubblize + 7" Overlay)	A 100	A 100	A 100	<=0.2	A 100	A 0	ASP
6	Reconstruct on Interstate	A 100	A 100	A 100	<=0.2	A 100	A 0	
7	Seal Joints and Cracks on Arterial (Curb & Gutter) (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	A 100	A 100	A 100	N –1	N –1	N -1	
8	Seal Joints and Cracks on Arterial (Non-curb & Gutter) (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	A 100	A 100	A 100	N –1	N –1	N -1	
9	Minor Rehab on Arterial l (Curb & Gutter) (Crack Sealing plus Clean & Reseal Joints, Partial Depth Patching, Grinding, Cross-Stitching, Slab Jacking, Full Depth Patching (**Not Greater Than:** 400 sq.yds.))	A 100	A 100	A 100	<=0.2	A 92	N -1	
10	Minor Rehab on Arterial (Non-curb & Gutter) (Crack Sealing plus Clean & Reseal Joints, Partial Depth Patching, Grinding, Cross-Stitching, Slab Jacking, Full Depth Patching (**Not Greater Than:** 400 sq.yds.))	A 100	A 100	A 100	<=0.2	A 92	N -1	
11	Major Rehab on Arterial (Curb & Gutter) (Minor Rehab. plus up to 800 sq.yds. Full Depth Patching plus 2" Saw & Seal Overlay)	A 100	A 100	A 100	<=0.2	A 92	A 0	COM
12	Major Rehab on Arterial (Non-curb & Gutter) (Minor Rehab. plus up to 800 sq.yds. Full Depth Patching plus 3.5" Saw & Seal Overlay)	A 100	A 100	A 100	<=0.2	A 92	A 0	COM
13	Major Rehab on Arterial (Non-curb & Gutter) (Minor Rehab. plus up to 800 sq.yds. Full Depth Patching plus 3.5" Saw & Seal Overlay)	A 100	A 100	A 100	<=0.2	A 92	A 0	COM
14	Rubblize and Overlay on Arterial (Non-curb & Gutter) (Rubblize + 5" Overlay)	A 100	A 100	A 100	<=0.2	A 100	A 0	ASP
15	Seal Joints and Cracks on Collector (Curb & Gutter) (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	A 100	A 100	A 100	N –1	N –1	N -1	
16	Seal Joints and Cracks on Collector (Non-curb & Gutter) (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	A 100	A 100	A 100	N –1	N –1	N -1	
17	Minor Rehab on Collector (Curb & Gutter) (Crack Sealing plus Clean & Reseal Joints, Partial Depth Patching, Grinding, Cross-Stitching, Slab Jacking, Full Depth Patching (**Not Greater Than:** 400 sq.yds.))	A 100	A 100	A 100	<=0.2	A 92	N -1	
18	Minor Rehab on Collector (Non-curb & Gutter) (Crack Sealing plus Clean & Reseal Joints, Partial Depth Patching, Grinding, Cross-Stitching, Slab Jacking, Full Depth Patching (**Not Greater Than:** 400 sq.yds.))	A 100	A 100	A 100	<=0.2	A 92	N -1	
19	Major Rehab on Collector (Curb & Gutter) (Minor Rehab. Plus up to 800 sq.yds. Full Depth Patching plus 2" Saw & Seal Overlay)	A 100	A 100	A 100	<=0.2	A 92	A 0	COM
20	Major Rehab on Collector (Non-curb & Gutter) (Minor Rehab. Plus up to 800 sq.yds. Full Depth Patching plus 3.5" Saw & Seal Overlay)	A 100	A 100	A 100	<=0.2	A 92	A 0	COM
21	Major Rehab on Collector (Non-curb & Gutter) (Minor Rehab. Plus up to 800 sq.yds. Full Depth Patching plus 3.5" Saw & Seal Overlay)	A 100	A 100	A 100	<=0.2	A 92	A 0	COM
22	Rubblize and Overlay on Collector (Non-curb & Gutter) (Rubblize + 5" Overlay)	A 100	A 100	A 100	<=0.2	A 100	A 0	ASP

Table 17

Continuously reinforced concrete pavements distress indices reset values

#	DESCRIPTION	LONG	TRCK	PATCH	ROUGHNESS	PAVETYPE
1	Minor Rehab on Interstate (Not Greater Than: 200 sq.yds. of Full Depth Patching & 4" A.C. Overlay)	A 100	A 100	A 100	A 92	COM
2	Major Rehab on Interstate (Not Greater Than: 400 sq.yds. of Full Depth Patching & 8" A.C. Overlay or Bonded Concrete Overlay)	A 100	A 100	A 100	A 92	COM
3	Reconstruction or Unbonded Concrete Overlay on Interstate	A 100	A 100	A 100	A 100	
4	Minor Rehab on Other (Not Greater Than: 200 sq.yds. of Full Depth Patching & 4" A.C. Overlay)	A 100	A 100	A 100	A 92	COM
5	Major Rehab on Other (Not Greater Than: 400 sq.yds. of Full Depth Patching & 8" A.C. Overlay or Bonded Concrete Overlay)	A 100	A 100	A 100	A 92	COM
6	Reconstruction or Unbonded Concrete Overlay on Other	A 100	A 100	A 100	A 100	

METHODOLOGY

Research Approach

Scope of Research

In order to accomplish the objectives of the research study, the scope of the proposed project as per phase was designed as follows:

Phase I- Review and Project Selection.

- Study the state-of-the-practice of all DOTD districts regarding the processes or the steps used in the evaluation of deteriorated pavement sections and the selection of candidate projects and their boundaries for treatments. All such procedures will be synthesized.
- Establish an experiment design matrix based on the information obtained from all districts. The matrix will include information regarding:
    - The types of pavement distresses, their extent, and severity levels prior to the application of the treatment.
    - The estimated remaining service life (RSL) of the pavement section before treatment and the estimated service life of the treatment.
    - The types of pre-treatment repairs applied to the deteriorated pavement projects.
    - The pavement age, pavement class, pavement materials types, layer thicknesses, and traffic volumes.
    - Construction practices.
- Identify and select pavement projects based on the information included in the experiment design matrix with all the good historic record of performance, age, treatments, traffic thickness, materials, etc.
- For each of the project identified in the previous step, obtain the following information from various districts and pavement management system (PMS) of DOTD:
    - The cost of all treatments including the cost of pre-treatment actions and excluding the cost of other types of work such as shoulder, guard rail, and other safety improvements.
    - The historical records regarding the types and costs of routine and heavy maintenance and preservation actions (data from MATTS, TOPS, LETS, etc.).
    - All available time series pavement distress data prior to and after the application of the treatment. These include the remaining service life (RSL) of the pavement sections prior

to treatment and the estimated service life of the treatment.

Phase II- Performance Modeling and Costs and Benefits of Treatments.

- Analyze the performance of all pavement sections prior and after treatment using the PMS distress data.
- Compare the costs and performance of pavement sections with and without treatments and their life extension based on the treatment.
- Evaluate the pavement treatment selection models along with associated trigger and reset values of indices for various treatment actions.
- Conduct regression analysis to develop pavement treatment models for each pavement type and distress type.
- Update pavement treatment selection models based on performance data and the experience gained over time.
- Based on the type and causes of pavement distresses in the state of Louisiana, analyze and recommend a process for identifying the optimal timing for the application of rehabilitation actions and/or preventive maintenance treatments.
- Develop guidelines for the implementation of cost-effective pavement preservation strategies that would maximize the user and agency benefits and minimize their costs.

Phase III- Model Integration and Training.

- Design the model with software to evolve by allowing performance data from future PMS data collections to be installed into the model, and thereby modifying the performance curves.
- Design the life cycle cost analysis (LCCA)/performance model software to be updated with changing construction costs to items and evolving performance curves.
- Integrate all models into the DOTD PMS, pavement preservation system, and pavement design system.
- Train the DOTD staff and engineers to use all models developed in this study using actual pavement data of a model district. A hand on group training will be held for LTRC, PMS, pavement preservation, and pavement design sections of DOTD.

Research Plan

The overall research plan for this study is graphically depicted in the form of a flow chart in Figure 13. Two main databases were utilized for the generation of the various pavement models: (a) pavement distress data and (b) historical data. The pavement distress data were obtained through DOTD's PMS ongoing data collection program of all distress information throughout the state of Louisiana. The historical data of when projects were completed were extracted from the Tracking of Projects System (TOPS), project letting schedule (LETS), and design and as build files in mainframe database. Both of these databases were obtained from the PMS section. The two databases were merged into one main database.

Once the main database was generated, all roadways where different treatment projects were implemented were identified. For each pavement project, various tables were generated to include as a minimum of the information such as data source, project/section identification number (control section, log-mile, project number, etc), route name and number (I-10, LA-1, US-90, etc), highway functional classification (interstate, arterial, collector, local, etc) pavement performance data (distress data, i.e. cracking, IRI, and rutting) before and after treatment, type and cost of the treatment action, type and thickness of the overlay, year/age of construction of treatments, traffic data, (ADTT, ESAL, etc.), and all possible maintenance actions (crack repair, grinding and milling, etc.).

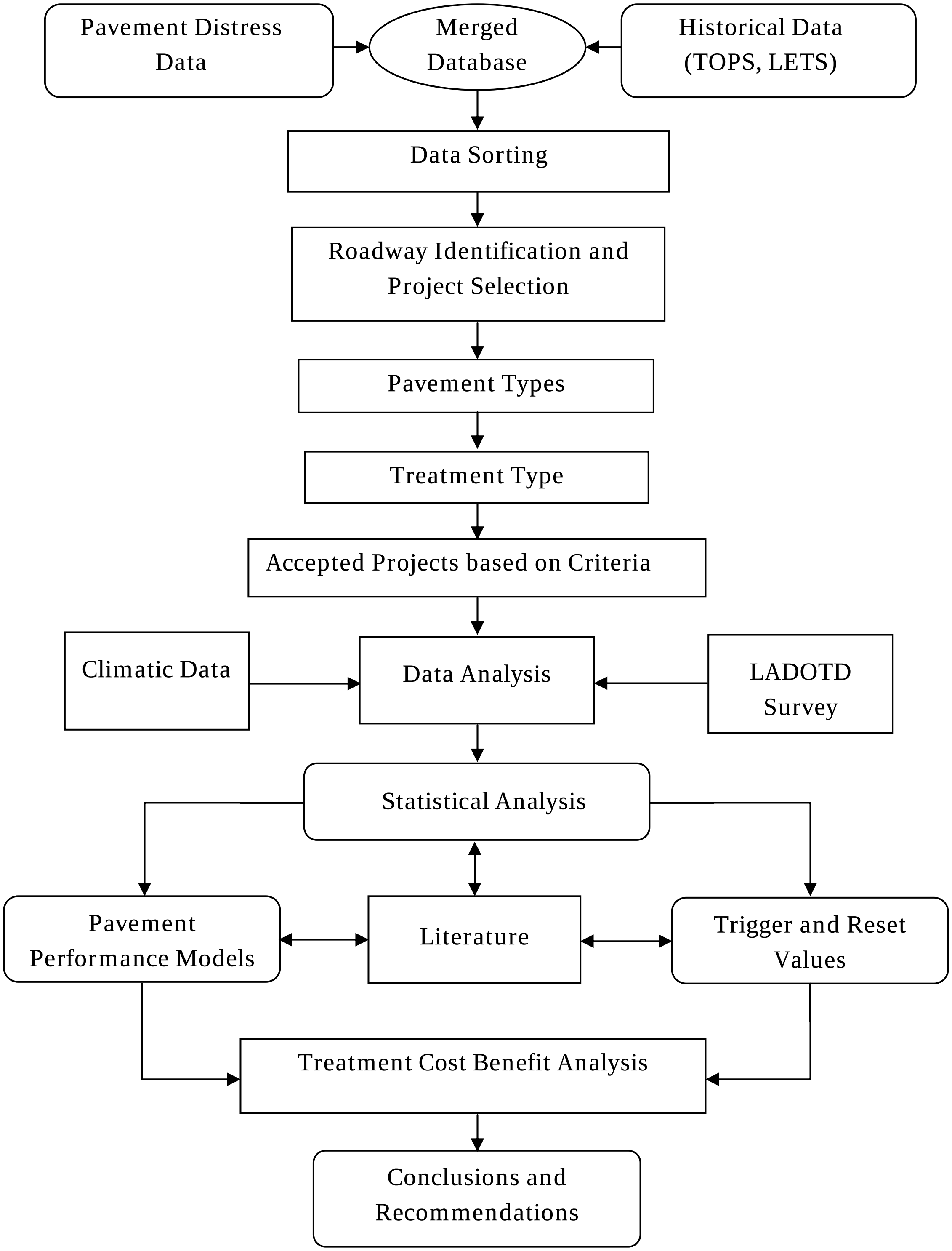


Figure 13
Flow chart representing the research approach for the study

The tabulated information was then used to select the various pavement sections relative to the available time series treatment performance data (distress data). All pavement sections having three or one distress data point just before the treatment application (BT) and three or more distress data points after treatments (AT) were selected for analysis.

In order to analyze treatment performance and to establish treatment trigger values, two criteria had to be met for both the before-treatment (BT) and after-treatment (AT) time-series distress data to accept a pavement section (1/10th mile) within a project. Any rejected pavement sections (BT, AT, or both) could not be used to model pavement performance and were therefore kept away from the analysis. Criteria one was the available three points before and after treatment. Criteria two was positive gain in distress BT and AT based on the best-fit curve. In order to develop treatment performance models, only one data point before the treatment and three points after treatment with positive gain in distress would satisfy acceptance criteria.

The accepted projects were then divided into four groups, based on the pavement type. The four pavement types were flexible pavement (ASP), composite pavement (COM), jointed concrete pavement (JCP), and continually reinforced concrete pavements (CRC). The pavement types were further divided based on the type of treatments including overlay, chipseal, microsurfacing, and replacement. Climatic data for each project were also generated.

Statistical analysis was used to develop regression models for pavement performance models. Treatment transition matrices were used to produce treatment trigger and reset values. Based on extensive literature review and study, a treatment cost benefit analysis was developed as a guideline for future treatment selection and application. Finally, based on the results and analyses of data, various conclusions and recommendation were drawn. After the completion of both Phase I and Phase II of the study, Phase III will commence which includes the software development and model integration.

To this end, detailed research methodology has been presented as follows.

Review of Literature and State-of-the-Practice

The research team conducted a comprehensive examination and review of existing literature regarding the state-of-the-practice in the USA and abroad about various aspects of pavement treatment such as pros and cons, treatment performance, and costs. Previous and ongoing research projects and case studies were thoroughly reviewed and summarized.

Review of DOTD State-of-the-Practice

The state-of-the-practices of the various districts related structural and preventive pavement treatments were evaluated through a survey questionnaire. The contents of the questionnaires included the following:

- The project scoping process and the factors affecting the selection of deteriorated pavement section for pavement treatments and the selection of construction methods.
- The types of forensic investigation or tests that are conducted to determine the possible causes of distress prior to the selection of the treatment.
- The factors affecting the determination of the type and extent of pre-treatment repairs.
- The remaining service life, the distress indices and the International Roughness index (IRI) values at which the deteriorated pavements are considered for treatments.
- The degrees to which the PMS distress data are used in deciding to restore pavement conditions.
- The distribution, the average, and the standard deviation of the service life of each pavement treatment. The time in years between the end of construction of the treatment and the appearance of cracking or other distresses.
- The process or procedures used by each district to restore pavement conditions.
- The treatment methods used by the districts for the rehabilitation and restoration of deteriorated pavement sections and their associated costs and pavement life extension.

The questionnaires were designed with the help of the members of the Project Review Committee (PRC) and then mailed to all District Engineers. The responses of all districts were tabulated and the results were summarized and presented in this report. A copy of the survey questionnaire is attached in Appendix B.

Roadway Identification and Project Selection

All roadways where different treatment projects were implemented were identified, with the help of the PMS office, PRC, and district engineers. For this purpose, DOTD databases were searched including the pavement management system (PMS) database, material testing system (MATT), tracking of projects (TOPS), letting of projects (LETS), the Highway NEEDS, the traffic & planning highway inventory, the maintenance operations system, the traffic volumes data, and the pavement design and system preservation database.

The research team searched the entire pavement network database in order to a) capture the effects of the variability of the state-of-the-practice of the districts on pavement treatment performance, and b) to identify the variables controlling the cost and performance of pavement treatments. For each pavement section, various tables were generated to include as a minimum of the following information.

- Data source,
- Project/Section identification number (control section, log-mile, project number, etc),
- Route name and number (I-10, LA-1, US-90, etc),
- Roadway classification (National Highway System, NHS (Interstate and others); State Highway System, SHS; and Rural Highway System, RHS),
- Pavement performance data (distress data) before and after treatment,
- Type and cost of the treatment action,
- Type and thickness of the overlay,
- Year/age of construction of treatments,
- Traffic data, (ADTT, ESAL, etc.), and
- All possible maintenance actions (crack repair, grinding and milling, etc.).

The tabulated information was then used to sort the various pavement sections relative to the available time series treatment performance data (distress data). The data sorting was based as follows:

- All pavement sections having, as a minimum, three distress points before and three or more distress points after treatment (for treatment effectiveness).
- All pavement sections having, as a minimum, one distress points before and three and more distress points after treatment (for treatment performance modeling).

The pavement sections in both above categories were further scrutinized relative to the available information regarding the treatment type, costs, the pre-treatment repairs, and so forth.

Project Acceptance Criteria for Treatment Effectiveness

The first and most critical step in quantifying the effectiveness of pavement treatments is to identify various candidate pavement projects for analysis. A candidate pavement project must have pavement condition data available for a minimum of three data collection cycles before and three data collection cycles after the treatment. The reason is that a minimum of three data points are required to model the non-linear pavement performance. In addition, the candidate pavement sections must not have had any additional treatments applied during the analysis period, since the objective is to study the effects of one given treatment.

The following steps were taken to identify pavement projects from the pavement management system (PMS) databases.

1. Determine the treatment type(s) to be analyzed.

2. Determine the possible range of years where the database could contain enough data to properly model the pavement performance. It was found that, based on data collection frequency, the appropriate range of treatment years for Louisiana is 2001 to 2004.
3. Identify pavement projects where the treatment type(s) determined in Step 1 were applied within the range of time specified in Step 2.
4. Check if any other treatments were applied within the range of available data which would shorten the availability of data to less than the required three data points before and after treatment.

Once the candidate projects were identified, the following criteria must be met for both the before-treatment (BT) and after-treatment (AT) time-series distress data to accept a pavement section (1/10th mile) for use in the analyses. Any rejected pavement sections (BT, AT, or both) cannot be used to model pavement performance and are therefore kept from the analysis.

A. **Minimum of three data points.** A minimum of three data points were required to fit any non-linear model, as any model can be fit to two or to one data point. Figure 14 shows example of BT acceptance and AT rejection of criteria A.

B. **Positive gain in distress based on the best-fit curve**. The appropriate model (see Table 18) was fit to the data and the parameters of the model were determined. Negative best-fit β, ω, θ, or μ (depending on the model) implies that the distress is "healing" with time and consequently the service life is infinite. Figure 15 shows an example of BT acceptance and AT rejection of criteria B.

Climatic Data and Indices

Weather Stations. Climatic parameters such as temperature and precipitation are the most important environmental factors that have considerable effects on the pavement distress. DOTD does not have a complete database for climatic data, so it was deemed necessary to make a climatic database for this study. For this purpose, 20 weather stations encompassing Louisiana were selected based on data availability (Table 19). The selection was made so as to cover all parts of Louisiana. Among the 20 weather stations from the National Climatic Data Center (NCDC), 17 of them were in Louisiana, 2 in Texas and 1 in Mississippi. Each station's geographical latitude, longitude co-ordinate and elevation from mean sea level (MSL) were recorded. For climatic data, daily maximum, minimum and mean temperature as well as daily precipitation values from year 2000 to 2010 were collected.

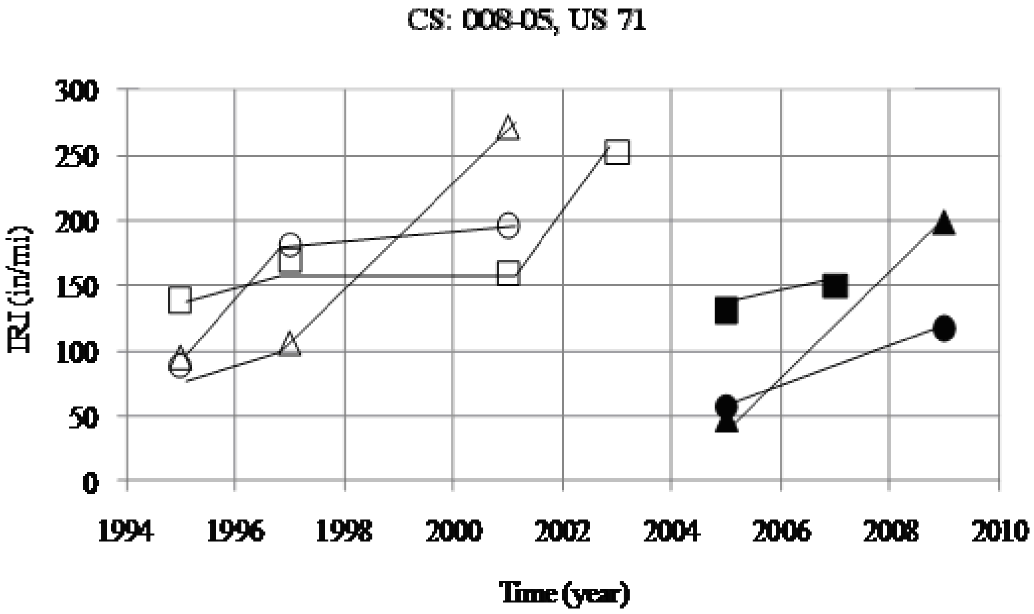


Figure 14
Criteria A, BT acceptance and AT rejection

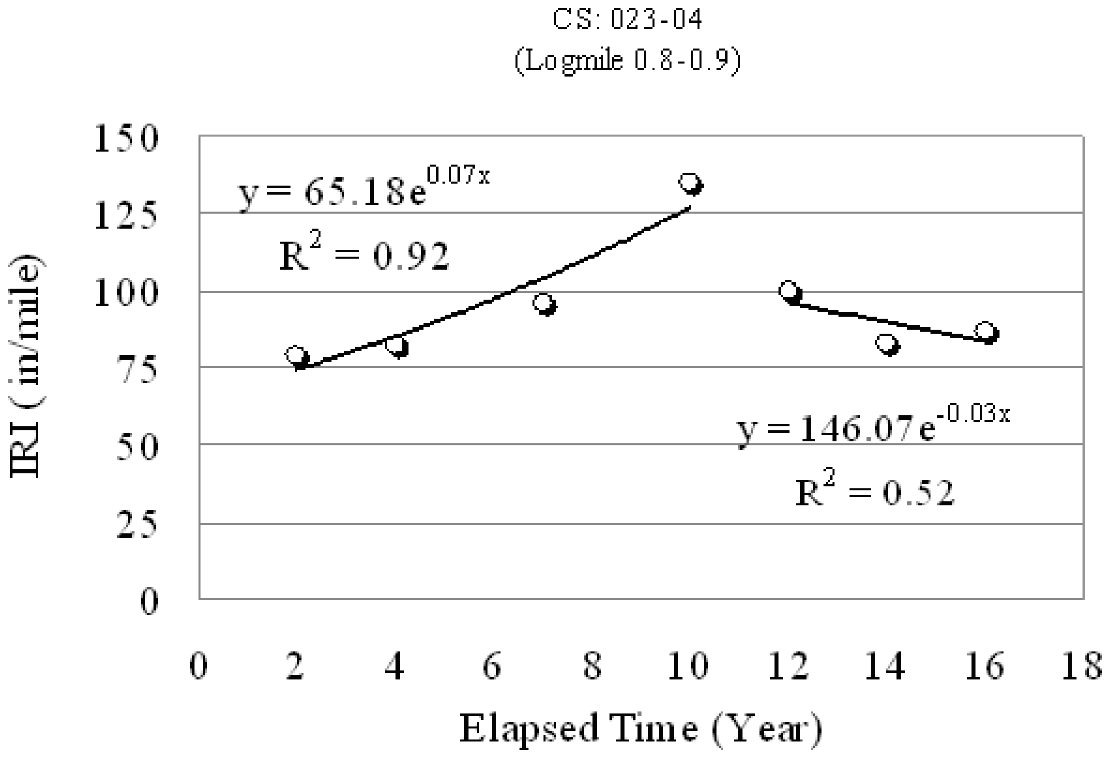


Figure 15
Criteria B, BT acceptance and AT rejection

Table 18
Common pavement distress models

Form of equation (use)	Pavement distress type (model form)		
	IRI (exponential)	Rut depth (power)	Cracking (Logistic (S-shaped))
Generic equation (modeling)	$IRI = \alpha \exp^{t\beta}$	$Rut = \gamma\, t^{\omega}$	$Crack = \frac{Max}{1 + \exp^{(\theta + \mu t)}}$
Derivative (slope)	$\alpha\beta \exp^{(t\beta)}$	$\gamma\omega t^{(\omega-1)}$	$-\frac{Max\, \mu \exp^{(\theta+\mu t)}}{\left[\exp^{(\theta+\mu t)}+1\right]^2}$
Integral (performance area)	$\left(\frac{\alpha}{\beta}\right)\exp^{(t\beta)}$	$\frac{\gamma t^{(\omega+1)}}{(\omega+1)}$	$Max\left\{t - \frac{\log\left[\exp^{(\theta+\mu t)}+1\right]}{\mu}\right\}$
Time to reach threshold (LE)	$t = \frac{\ln\left(\frac{Threshold}{\alpha}\right)}{\beta}$	$t = exp\left[\frac{ln\left(\frac{Threshold}{\gamma}\right)}{\omega}\right]$	$t = \left[\frac{1}{\alpha}\left(\ln\left(\frac{Max}{Threshold}\right)-1\right)\right]-\left(\frac{\beta}{\alpha}\right)$
Where, α, β, γ, ω, θ, and μ are regression parameters (α, γ, θ are intercepts and β, ω, μ are slopes) t = elapsed time (year), and Max = the maximum value of cracking			

After collecting the climatic data, it was necessary to interpolate data for each project from nearby weather stations. The geographical latitude and longitude co-ordinate of each project beginning log-mile (BLM) were recorded from DOTD PMS data and inverse distance weighting method was used for interpolation. Inverse distance weighting method is based on the assumption that the nearby values of the stations contribute more to the interpolated values than remote observations. The effect of a known data point is inversely related to the distance from the unknown location that is being interpolated. This method is efficient and intuitive and interpolation works best with evenly distributed points *[2]*. The following equation was used:

$$W_g = \frac{1}{\sum_{i=1}^{i=n} \frac{1}{d_i^2}} \sum_{i=1}^{i=n} \left(\frac{1}{d_i^2} W_i\right) \tag{5}$$

Where, Wg equals estimate at a specific control section, g; Wi equals observations at "n" nearby weather stations i equals 1 to n; and di equals distance from control section g to station i.

For this research, n was taken as 4, indicating that for each project four nearby weather stations were taken into account for climatic data interpolation. A comprehensive routine was developed using Matrix Analysis Laboratory (MATLAB) software for this analysis. Using the climatic data, various temperature and precipitation indices were developed as discussed below.

Table 19

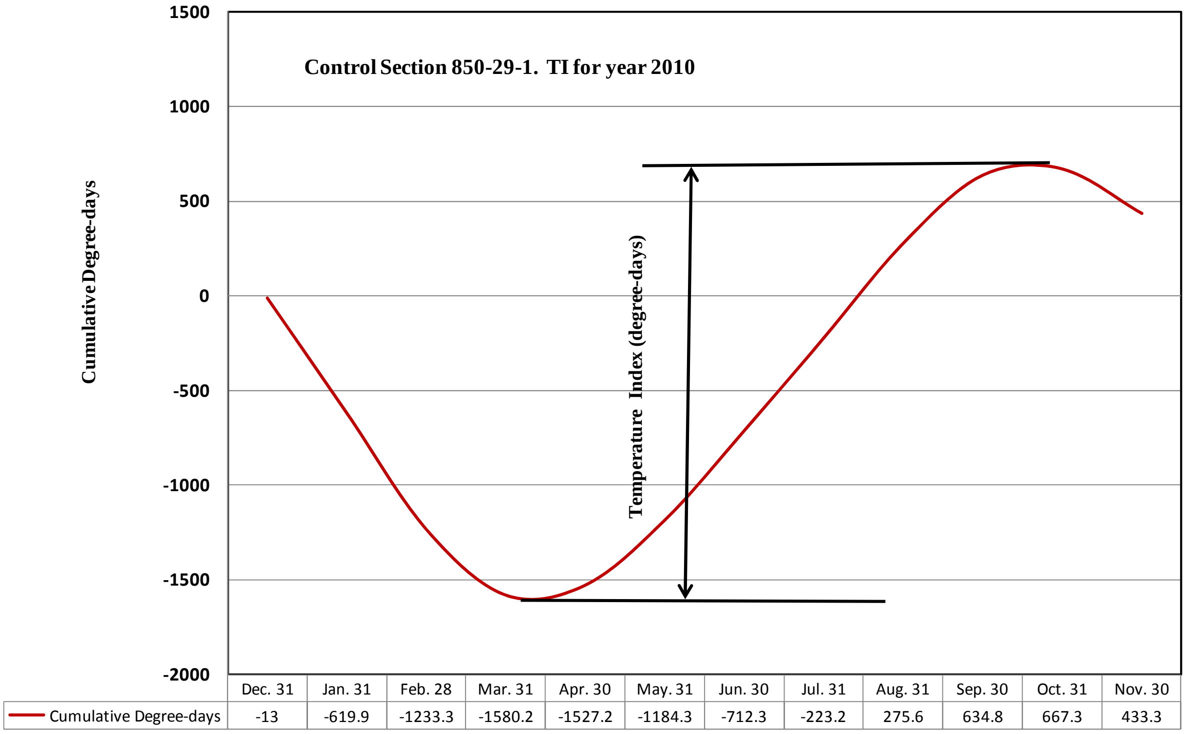
List of weather stations used for the study

Weather Station	Latitude	Longitude	Elevation from Mean Seal Level (ft)
Alexandria	31.31°	-92.45°	87
Baton Rouge	30.53°	-91.13°	64
Fort Polk	31.13°	-93.23°	28
Hammond	30.50°	-90.36°	35
Houma	29.45°	-90.30°	5
Lafayette	30.20°	-91.98°	38
Lake Charles	30.11°	-93.21°	9
MCCOMB	31.16°	-90.46°	413
Monroe	32.50°	-92.03°	79
Natchez	31.58°	-91.33°	195
Natchitoches	31.56°	-93.46°	255
New Iberia	29.95°	-91.70°	20
New Orleans	29.98°	-90.25°	4
New Orleans	29.78°	-90.10°	3
Orange	30.21°	-93.73°	18
Patterson	29.68°	-91.20°	5
Ruston	32.53°	-92.68°	260
Shreveport	32.43°	-93.81°	254
Slidell	30.33°	-89.81°	27
Tallulah	32.38°	-91.18°	85

Temperature Index. Most researchers in the past used the freezing index (FI) as one of the parameters for predicting cracking model *[3], [4], [5]*. However, Louisiana's temperature occasionally falls below freezing; furthermore, based on the long term pavement performance (LTPP) database, the state falls under wet-no-freeze zone. It was also noticed from the climatic data that only few days in a year were below freezing temperature. Hence for Louisiana, a new Temperature Index (TI) similar to FI was introduced to evaluate the effect of temperature *[6]*. This temperature index was developed to observe the variation of temperature for a pavement throughout the whole year. The yearly average temperature from 2000 to 2010 was calculated for all 972 pavement projects encompassing Louisiana. The average temperature observed was 67.41 °F (19.67 °F). Therefore, 68°F (20 °C) was selected as a base temperature after rounding off to calculate TI as explained below.

A negative one-degree day represents one day with a mean air temperature one degree below 68°F, a positive one-degree day indicates one day with a mean air temperature one degree above 68°F. The mean air temperature for a given day is the average of high and low temperatures during that day. If the mean air temperature is 85°F on the first day and 72°F on the second and 63°F on the third day, the total degree days for the three-day period are (85-68) + (72-68)+ (63-68) = 16 degree-days. The degree-days for each month were similarly calculated. A plot of cumulative degree-days versus time for control section 850-29-1 for year 2010 was plotted and it resulted in a curve, as shown in Figure 16. The difference between the maximum and minimum points on the curve during one year is called the TI for that year.

Figure 17 portrays average values of TI for pavements subjected to overlay treatment for all nine districts for year 2008. It is obvious from the Figure 17 that TI differs substantially from district to district. Similarly, from Figure 18, one can see the effect cumulative TI for different projects at different districts . Hence, the TI is good indicator of differentiating project sites and incorporating the effect of temperature on pavement performance.



	Dec. 31	Jan. 31	Feb. 28	Mar. 31	Apr. 30	May. 31	Jun. 30	Jul. 31	Aug. 31	Sep. 30	Oct. 31	Nov. 30
Cumulative Degree-days	-13	-619.9	-1233.3	-1580.2	-1527.2	-1184.3	-712.3	-223.2	275.6	634.8	667.3	433.3

Figure 16

Determination of temperature index

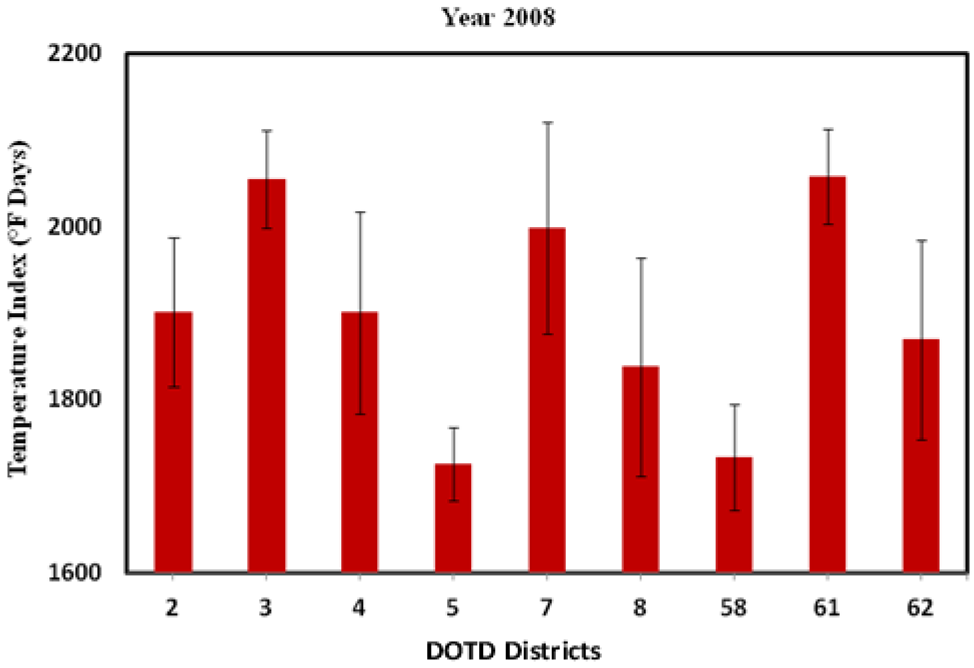


Figure 17

TI for selected overlay projects as a function of DOTD districts

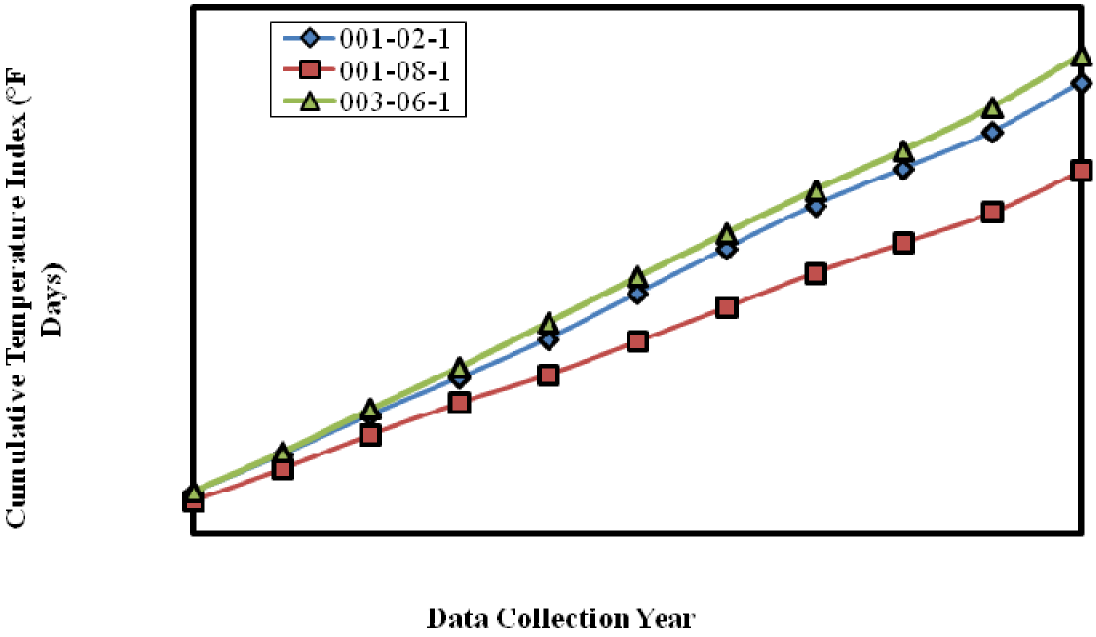


Figure 18

Cumulative temperature index for different projects

Low Temperature Index. Although Louisiana temperature rarely exhibits below 0°C (32°F), there were variations between colder temperatures at different regions. Northern regions of Louisiana suffer colder temperature than southern regions. To study the effect of cold temperature, the Low Temperature Index (LTI) was introduced in this study, in which 39.2°F (4°C) was used as the threshold temperature as shown below.

$$LTI = \sum(39.2 - T_m), T_m \leq 39.2°F \tag{6}$$

Where, LTI equals Low Temperature Index, (°F-Days) in a year, and T_m equals Mean Daily Temperature (°F). For example, project 005-09-0033 is located in District 2 (southern part) has a LTI value of 8.27 (°F-Days) compared to LTI value of 109.03 (°F-Days) for project 025-08-0053 which is located in District 4 (northern part) for year 2000. This difference could contribute to performance of the pavement and hence be considered while developing distress models. Figure 19 shows average values of LTI for pavements subjected to overlay treatment with standard deviation for all nine districts for the year 2008. Clear variations from district to district can be observed in LTI values. It is also obvious from Figure 20 that different projects will experience different magnitude and rate of accumulation of LTI over the period of time.

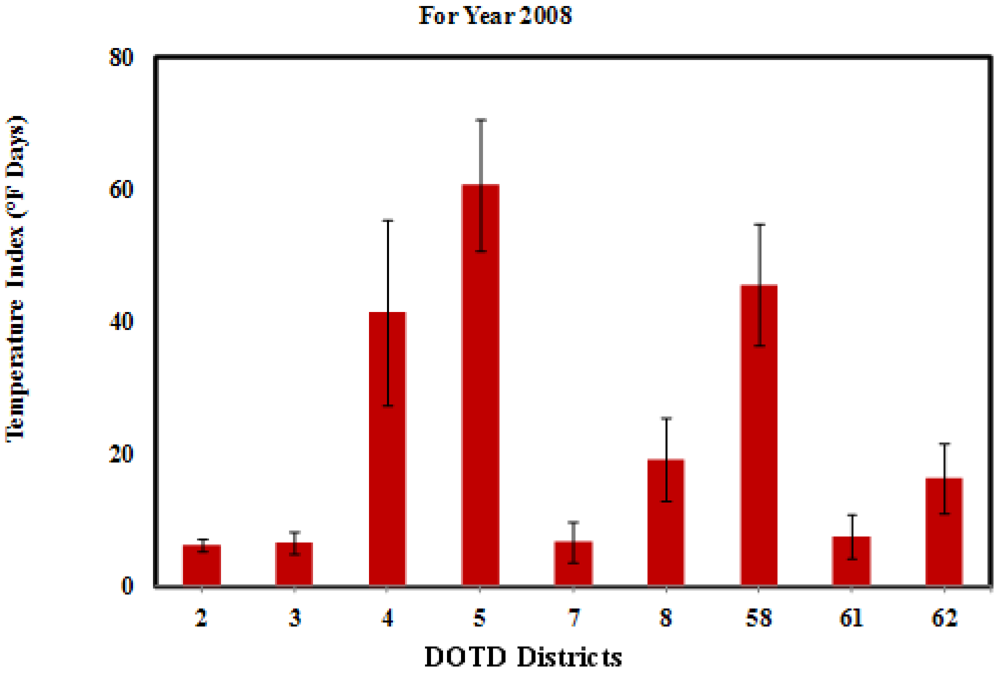


Figure 19

LTI for selected overlay projects as a function of DOTD districts

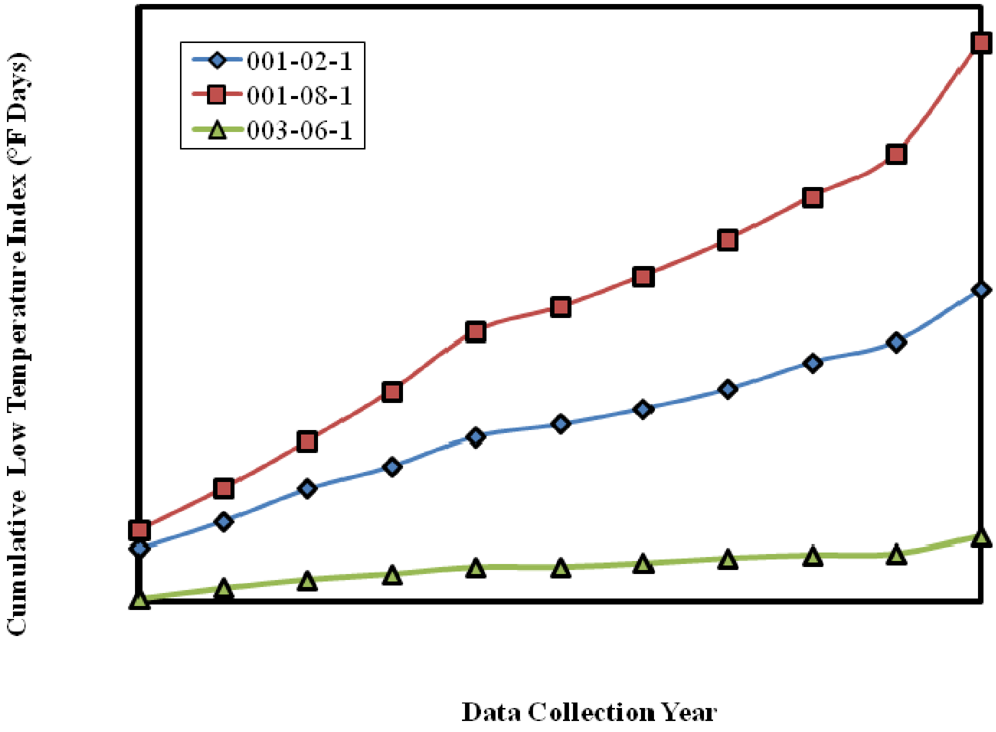


Figure 20
Cumulative low temperature index for different projects

Precipitation Index. To evaluate the effect of precipitation, a new precipitation index (PI) was introduced in this study. The PI is the product of precipitation per year and number of days of precipitation in that year as shown below.

$$PI = P.N_p \qquad (7)$$

Where, PI is the precipitation index (in-days), P is the precipitation/year (in), and Np is the number of days of precipitation in that year.

The PI represents the amount and exposure of pavement to moisture that is responsible for pavement damage in a year. Figure 21 shows average values of PI for pavements subjected to overlay treatment in various districts. It can be seen that PI values are different for each district. Similarly, the effect of cumulative PI is illustrated in Figure 22 for three different projects over the years.

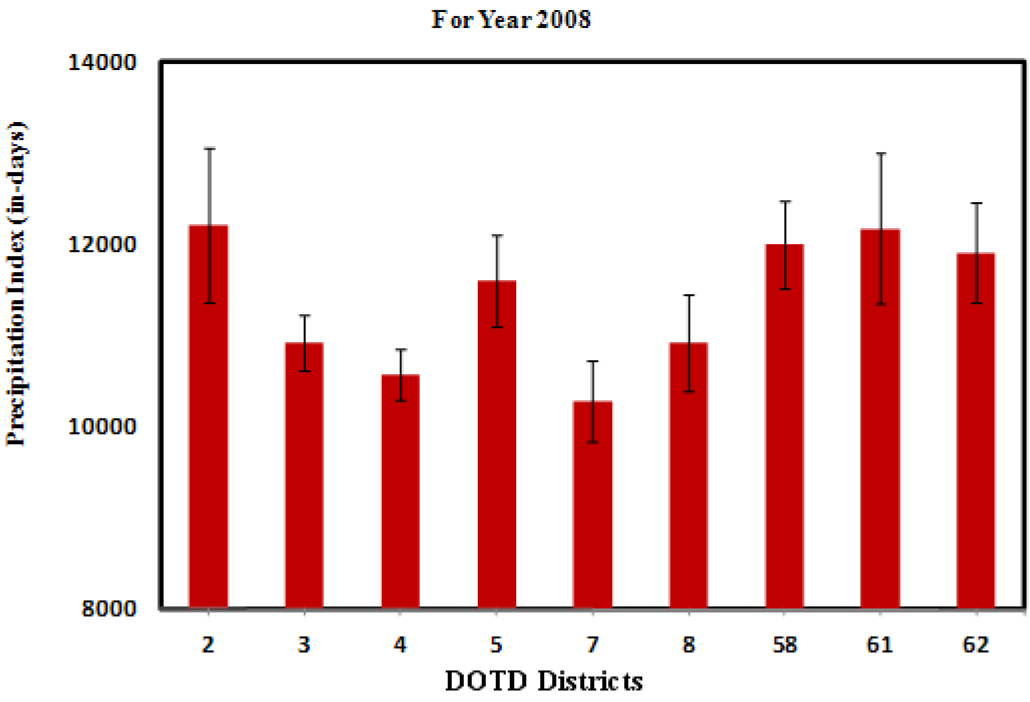


Figure 21
PI for overlay projects as a function of DOTD districts

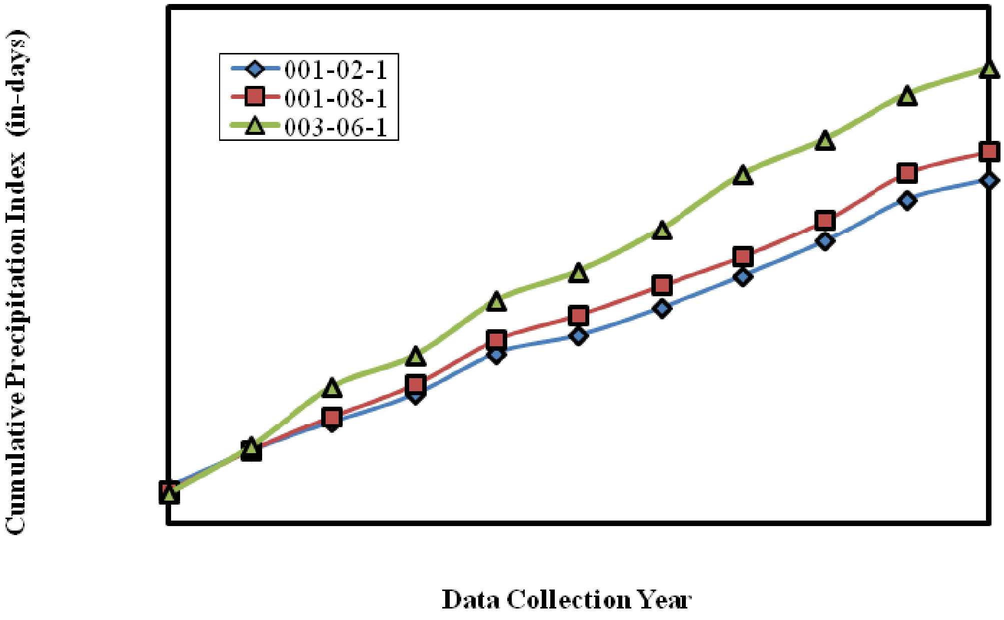


Figure 22
Cumulative precipitation index for different projects

Regression Analysis

The forward stepwise regression procedure is probably the most widely used procedure to develop a simple linear regression model. It economizes the computational effort and develops a sequence of models at each step adding or deleting a variable.

For regression analysis, the variables were first selected based on past research, literature review, and, to some extent, engineering judgment. Performance models based on statistical analysis generally recognize that major factors contributing to the model can be divided into two parts: variables related to distresses like cracking, rutting, spalling, and faulting; and variables related to non-distress, like site factors, age of pavement, traffic loading, precipitation, temperature, freezing index, cooling index, and thickness of pavement layers. All such models are statistically based and the main advantage is their simplicity. However, the resulting models are applicable only within the range of the data used for the development of the model. These models need calibration when used out of their boundary conditions and often the form of the model has to be modified.

Correlation Matrix

In this analysis, dependent variables such as site factors, functional classification, age of pavement, traffic loading (ESAL), precipitation index, temperature indices, and thickness of pavement layers were used to find the most appropriate combination. For this purpose, a correlation matrix was developed for all the variables. Table 20 shows a typical example of correlation matrix.

Table 20
Typical correlation matrix of variables

	IRI (in/mile)	*t*	*FC*	*HMA*	*PCC*	*CESAL*	*PI*	*CTI*	*IRIp*	*SD*
IRI (in/mile)	1.00									
t	0.19	1.00								
Fn	0.04	-0.15	1.00							
T_{HMA}	-0.10	0.02	0.07	1.00						
T_{PCC}	-0.08	0.06	-0.23	0.45	1.00					
CESAL	0.23	0.50	-0.34	-0.04	0.03	1.00				
PI	0.19	0.24	0.19	0.28	0.22	0.13	1.00			
CTI	0.19	0.98	-0.10	0.07	0.07	0.50	0.28	1.00		
IRIp	0.39	-0.09	0.40	0.06	-0.13	-0.15	0.05	-0.09	1.00	
SD	0.64	0.18	-0.04	-0.14	-0.18	0.22	0.08	0.17	0.29	1.00

From the previous correlation matrix, it can be interpreted that the thickness of pavements shows negative correlation which supports the engineering judgments. Other dependent variables show positive correlations and some of them have very strong relationship with IRI. Also, it can be concluded from the matrix that there is no collinearity between any of the variables and they can be used for linear regression.

Analysis of Variance (ANOVA)

Linear regression analyses were conducted to determine the regression models for treatments and various outputs were obtained as shown Table 21. This includes the multiple R, R squared, adjusted R squared, standard error, the number of observations, and analysis of variance (ANOVA) table for the regression. The output summary also included the degrees of freedom, sum of squares, and mean sum of squares, F score, and p-value of F test. The final output consisted of coefficient data, such as coefficient, standard error, t-statistic, p-value, lower, and upper 95% confidence levels.

Table 21

Summary of regression outputs

Regression Statistics						
Multiple R	0.79					
R Square	0.63					
Adjusted R Square	0.62					
Standard Error	0.25					
Observations	280.00					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	5	29.738	5.948	91.876	0.000	
Residual	274	17.738	0.065			
Total	279	47.476				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.892535	0.189	10.007	0.000	1.520	2.265
(ln(CESAL)*Fn)/(T_{HMA}/T_{PCC}))	0.001518	0.000	3.498	0.001	0.001	0.002
ln(IRI_p)	0.272687	0.039	6.981	0.000	0.196	0.350
ln(SD)	0.310286	0.022	14.134	0.000	0.267	0.354
CTI *t	0.000001	0.000	2.168	0.031	0.000	0.000
PI	0.000014	0.000	1.927	0.054	0.000	0.000

Development of Treatment Performance Models

International Roughness Index (IRI) Model

Various researchers have shown that for both pre- and post-treatment pavements the IRI over time follows the shape of an exponential functional form *[7], [8], [9], [10]*. In this study, the treatment performance curve for IRI was also assumed to be an exponential model as shown in equation (8).

$$IRI = \alpha \exp^{t\beta} \tag{8}$$

Where, α and β are regression constants and *t* is the elapsed time or surface age of the treatment.

The measured IRI is the result of accumulation of damage due to repeated ESAL, so the cumulative ESAL was considered in IRI model. Pavement layer thickness is expected to have an important effect on the IRI. For the same traffic, climatic and soil conditions increasing the thickness of pavement provides more structural capacity and thus results in lower IRI values. Composite pavement has a layer of Portland Cement Concrete (PCC) underneath the hot mix asphalt (HMA) overlay. For predicting the IRI both of these thicknesses were considered because both of the layers provide structural strength to the pavement. The thickness of the overlay treatment is decided based on the condition of the pavement before the treatment is applied to the pavement and also the future traffic and site factors such as soil condition, base sub-base, and thickness of the PCC. For the same PCC thickness, higher the ratio of HMA/PCC, the pavement should suffer less damage. Also interstates and arterials have more reliability and higher design and construction standards than collectors and local road. So, for different highway classification the rate and magnitude of distress accumulation will be different. The functional classifications were assigned numbers as designated by DOTD (Interstate=1, ….., local=9).

If the condition of the pavement before treatment is not properly assessed, variation in pavement treatment performance is expected. In this study, it was observed that the IRI just before the treatment (IRI_p) had an effect on the rate of IRI after treatment. Similarly, the standard deviation (SD) of IRI after treatment for each year during the life span of treatment has a relationship with the IRI after treatment. Since each project consisted of numerous 1/10th –mile sections the average value corresponding to each year was used in modeling to reduce the effect of variations. It was found that for higher IRI values after treatment the higher the IRI standard deviation and vice versa. This can be attributed to project selection, project boundaries, and pre-treatment conditions and its application.

It was found that the cumulative temperature index (TI) had a great impact on pavement performance. TI represents the variation of temperature for a particular project and it had a significant effect on the IRI of pavements. Similarly, the PI represents the amount and exposure of pavement to moisture that is responsible for pavement damage in a year.

Rut Model Development

There are generally three distinct stages for the rutting behavior of pavement materials under a given set of material, load, and environmental conditions primary, secondary and tertiary stages *[11]*. This research study tries to predict the primary and secondary stage behavior as one which follows a concave trend with load repetitions and time which can be modeled as a power function as shown below.

$$Rut = \lambda t^{\beta} \tag{9}$$

The above equation can be written as:

$$ln(Rut) = ln(\lambda) + \beta \, ln \, t \tag{10}$$

Equation (10) became the basis for the regression analysis in this study. Rutting is the result of accumulation of damage due to repeated ESAL, so the cumulative ESAL was considered in the model. Pavement layer thickness is expected to have an important effect on the rut. For the same traffic, climatic, and soil conditions, increasing the thickness of pavement provides more structural capacity and thus results in lower rut depth. Composite pavement has a layer of Portland Cement Concrete (PCC) underneath the hot mix asphalt (HMA) overlay. For predicting the rut, both of these thicknesses were considered because both of the layers provide structural strength to the pavement. The thickness of overlay treatment is decided based on the condition of pavement before the treatment along with the future traffic and site factors such as soil condition, base, subbase, and thickness of the PCC. Similar to IRI model, the function classification of highways were also considered in the development rut model.

Rutting is expected to vary at different times of the year due to variation in temperatures. Rutting of HMA layers is more common during hot summer months than during the winter, and deformation is more likely to happen in wet spring months *[12]*. However, it was found that the temperature and precipitation indices developed during this study did not exhibit strong statistical significance pertaining to the regression model.

Cracking Model Development

Cracking is one of the major forms of distress in pavements which hinders ride quality and usually leads to rider discomfort, increased travel times, and higher operational cost for vehicles *[13]*. In addition to inducing roughness, the water seepage through the cracks and along with the debris accelerate the rate of deterioration of treatments and underlying pavement layers thus, reducing the pavement service life *[14]*.

Cracking pattern in a composite pavement tends to follow logistic (S-shaped) function *[11], [5]*.

$$Crack = \frac{Max}{1 + exp^{(-X)}} \tag{11}$$

Equation (11) can be written into the following form:

$$ln\left(\frac{Crack}{Max - Crack}\right) = X \tag{12}$$

Where, $X = a_o + a_1 . x_1 + a_2 . x_2 + a_3 . x_3 + a_4 . x_4 + \ldots\ldots\ldots\ldots .$

This formulation expresses the logistic function as generalized linear model and linear regression analysis becomes possible. But, in this formulation, if crack = 0, then the equation becomes undefined. To address this issue, a unit value of cracking per lane-mile in U.S. customary unit is added with the actual crack value.

$$ln\left(\frac{Crack + 1}{Max - (Crack + 1)}\right) = X \tag{13}$$

The above-generalized linear form of logistic function was utilized to model transverse, longitudinal, and fatigue cracking for overlay treatment of composite pavement.

In order to utilize equation (13), maximum magnitude of cracking for fatigue, transverse, and longitudinal cracking were determined as shown in

- For all pavements, alligator crack saturation level is 31680 ft^2 /lane-mile which means in a lane, two wheel paths with a width of 3 ft. will be fully cracked.
- For all pavement types, the recommended longitudinal crack saturation level is 200%. This is equivalent to two cracks along the entire mile-long pavement segment. This recommendation would yield a longitudinal crack saturation level worth 10560 ft/lane-mile.
- For flexible and composite pavements, the recommended crack saturation level for transverse cracking is based on transverse crack spacing of about 6 ft. (half the lane width). This should yield 880 transverse cracks in mile-long pavement segment. Thus, the total transverse crack saturation level, assuming 12-ft. cracks, is 10560 ft/lane-mile.
- For JCP, the recommended transverse cracking saturation level is based on a maximum of 100% slab cracking. Assuming 16-ft. slab length and one crack per slab, this would yield a maximum of 330 transverse cracks in 1-mile pavement. Assuming the length of each crack is 12 ft. (the width of the slab), the recommended transverse crack saturation level is 3960 ft/lane-mile

The 1/10th mile pavement segments that did not satisfy both of the project acceptance criteria were excluded from the analysis and then distress value for each project was calculated from the following equation.

$$C_r = \frac{\sum_{i=1}^{N} C_i}{N} * 10 \tag{14}$$

Here, C_r equals distress value /lane-mile for a particular project (ft^2/lane-mile for fatigue crack and ft/lane-mile for transverse and longitudinal cracking), N equals number of accepted 1/10th miles in the project, C_i equals cracking value of a single 1/10th mile section. It must also be noted that for this study that the low, medium and high severity cracks were added to find the total amount of cracks in a single 1/10th mile pavement.

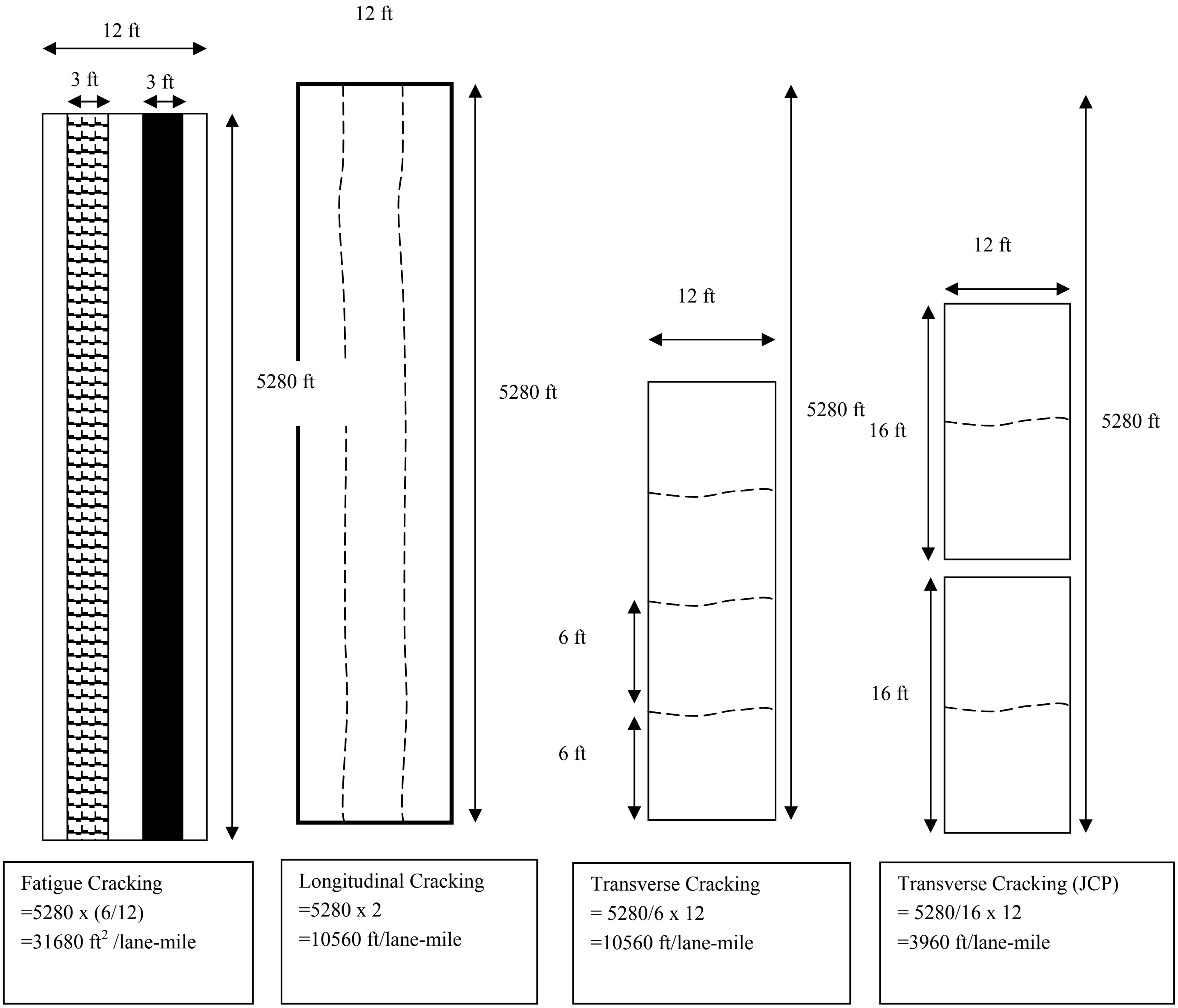


Figure 23
Illustration of maximum value of cracking

Assessment of the DOTD State-of-the-Practice

DOTD Distress Indices

For each pavement distress and condition type, DOTD calculates a distress index using the deduct points listed in Table 1 through Table 7. Each distress index is based on a numerical scale from 0 to 100, with 100 indicating very good pavement conditions (no distress). The time dependent distress index is then used to calculate the pavement remaining service life (RSL).

The distress indices for roughness and rut depths are stated in equations (2) and (4), respectively, listed in Table 8 and shown in Figure 11 and Figure 12. The roughness and rut indices remain at 100 for as long as the IRI is less than 50 inch/mile and the rut depth is less than 0.125 in. Both index values decrease linearly with increasing IRI and rut depth. The value of roughness index reaches its lowest value of 10 when the IRI is equal to or higher than 500 inch/mile. On the other hand, the rut index reaches zero value when the rut depth reaches 1.375 in.es or higher.

The calculations of the transverse, longitudinal, alligator, and random cracking indices are more involved than the roughness and rut indices. The cracking indices and deduct points are functions of the severity and extent of the cracking. For multiple severity of a certain crack type (such as transverse crack), the deduct points are the sum of the deduct point for low, medium, and high severity cracks and their associated extent. The index is the difference between 100 and the sum of the deduct points. Finally, for flexible and composite pavements, random cracking is the sum of longitudinal, transverse, and other cracks.

The assessment of the DOTD is based herein on the pre-determined deduct points for each pavement condition and distress type. Hence, such an assessment is divided to three areas: roughness, rut depths, and cracking.

Assessment of the DOTD Deduct Points for Roughness

DOTD deduct points for pavement roughness can be divided into two regions as stated below.

1. Deduct points = 0.0 for IRI equal to or less than 50 inch/mile. This range is very reasonable and consistent with the state-of-the-practice in pavement construction. The pavement surface smoothness of well-constructed flexible and concrete pavements would have IRI between about 30 and 50 inch/mile. In most scenarios, the IRI of well-constructed pavement is about 45 inch/mile. Note that 50 inch/mile correspond to about 4.2 on the AASHTO Pavement Serviceability Index (PSI).
2. The deduct points increase linearly from 0 to 90 as the IRI increases from 50 to 500 as shown in Figure 11. The corresponding roughness index decreases from 100 to 10. These deduct points appear to be reasonable.

For consistency purpose, and to make the roughness index parallel to the rut index, it is recommended that another deduct point of 100 be established for IRI of 550. This would make the lowest possible roughness index of zero, which would be consistent with the rut index addressed in the next subsection.

Assessment of the DOTD Deduct Points for Rut Depths

DOTD deduct points for pavement rut depths can also be divided into two regions as:

1. Deduct points = 0.0 for rut depths between zero and 0.125 in. This range is very reasonable because (given the pavement cross-slope) it is highly unlikely that water would stand in 0.125 in. rut depth. Hence, the probability of hydroplaning is very low.

2. The deduct points increase linearly from 0 to 100 as the rut depth increases from 0.125 to 1.375 in.es as shown in Figure 12. The corresponding rut index decreases from 100 to 0. These deduct points appear to be reasonable.

For continuity purpose and to make the deduct points for rut depth and the associated rut index conducive to modeling with respect to time, it is recommended that the deduct points for 0.125 in. rut depth only increase from 0 to 5. This modification would allow the DOTD to differentiate between pavements with zero rut depth and those where rut depth starts to show some accumulation.

Assessment of the DOTD Deduct Points for Cracking

The analyses and assessment of the DOTD deduct points for cracking yielded an entirely different scenario than that for roughness and rut depths. To illustrate the results and to avoid unnecessary repetitions, results of the analyses of the alligator cracking are discussed below along with the recommended remedies. The results for transverse, longitudinal, and random cracking are more or less similar to those of the alligator cracking; hence, only the remedies are presented.

As discussed earlier, the DOTD deduct points for alligator cracking are listed in Table 1 and depicted in Figure 4. It was found that:

1. The deduct points identify crack saturation point at 3,168 ft^2 of high severity alligator cracks. This is equivalent to 50% of the pavement area in question that has experienced alligator cracking. In most cases, the crack saturation is a theoretical cracking level used in modeling crack propagation over time using a logistic function.

2. The deduct points are not designed to indicate the time of crack initiation. The first deduct point is assigned when the alligator cracking reaches 51 ft^2 or higher. Knowledge of the crack initiation time is crucial in calibrating the alligator cracking model.

The deduct points for low, medium and high severity alligator cracking are not consistent and, in several scenarios, not compatible with the severity and extent of the alligator cracking. To illustrate, consider the severity and extent scenarios and the associated alligator cracking deduct points for the seven pavement segments listed in Table 22. It can be seen that, although pavement section 1 has the worst distress (the highest square footage of high severity and the highest total square footage of cracking) amongst sections 1, 2, and 3, it has the lowest deduct points and the highest alligator cracking index. Likewise, pavement section 4 has worse condition than 5, yet the deduct points for section 4 is less than that for section 5. The same scenario applies for pavement sections 6 and 7. The results of the seven pavement sections indicate that the deduct point system for alligator cracking needs to be calibrated to express the true condition ranking of the various pavement segments. For the three crack severity levels, the deduct points are not a continuous function of the extent of cracking as can be seen in Figure 4. Kinks in the curves can be seen between deduct points 43 and 50.

Table 22

Deduct points and distress index for hypothetical seven pavement sections based on existing DOTD deduct scheme

Section	Severity level	Low	Medium	High	Total cracking (ft2)	Total deduct points	Distress index
1	Extent (ft^2)	0.0	0.0	3168	3168		
	Deduct points	0.0	0.0	61		61	39
2	Extent (ft^2)	51	701	1301	2053		
	Deduct points	1	21	43		65	35
3	Extent (ft^2)	701	701	1301	2703		
	Deduct points	16	21	43		80	20
4	Extent (ft^2)	0.0	0.0	2401	2401		
	Deduct points	0.0	0.0	50		50	50
5	Extent (ft^2)	701	701	701	2103		
	Deduct points	16	21	29		66	34
6	Extent (ft^2)	0.0	0.0	1301	1301		
	Deduct points	0.0	0.0	43		43	57
7	Extent (ft^2)	0.0	600	701	1301		
	Deduct points	0.0	18	29		47	53

3. The weight factors between the low and medium and the low and high severity levels are variables increasing incrementally as the crack extent increases as listed in Table 23. The data in Table 23 is obtained by dividing the deduct points for each severity level and extent by the deduct points of the low severity level and the same extent. Although the weight factors for medium and high severity cracks are relatively low compared to the literature and the relative costs of maintaining low and high severity cracks, the factors could be based on

emphasizing the damage created by the crack initiation. That is, the damage has already been done when the crack appears as low severity. Such damage would increase over time to the medium and high severity levels.

Table 23
Existing DOTD weight factors between medium and low, and high and low crack severity levels.

Weight factor	Extent (ft^2)							Average weight factors
	0	51	701	1301	2401	3168	9999.99	
Low	-	1	1	1	1	1	1	1
Medium/low	-	1.0	1.3	1.4	1.4	1.8	1.8	1.4
High/low	-	1.0	1.8	2.0	2.0	2.2	2.2	1.7

4. The deduct points for low, medium, and high severity cracking levels are not consistent from one year to the next. The main reason is the cracking data and the assigned severity levels which are not consistent from one year to the next. They are affected by various factors including:

- The judgment of the surveyor who is reviewing the electronic images: his/her judgment is a function of the degree of training and experience. Further, the same pavement segment may not be reviewed by the same surveyor each year or each data collection cycle. Thus, a crack may be labeled high severity in one year could be labeled medium or low severity next year and vice versa. It also holds true for the image digitizing software.
- The pavement temperature at the time when the electronic images were obtained. High temperatures cause the crack opening to decrease, which may cause changes in the crack severity level.
- Low or medium severity cracks in one year will naturally propagate to medium and high severity in few years. Such propagation causes erratic changes in the calculated time dependent deduct points, which causes uncertainty in modeling the deduct points as a function of time and the remaining service life (RSL). Although knowledge of the time at which each crack has propagated in extent and from low to medium and from medium to high severity levels would assist in the development of accurate crack propagation model, it is not practical to track every crack unless each crack location is referenced using GPS data.

The above factors precipitate erratic behaviors in the plots of low, medium, and high severity cracking data against time as shown in Figure 24. The problem in the analysis of the cracking data could be partially solved by summing the three severity levels as shown in the Figure 24. Thus, the low, medium, and high severity cracking data could be used to estimate the cost of pavement treatment. On the other hand, the sum of the low, medium and high severity cracks should be used in the analysis. Indeed, most pavement prediction models used in M-E PDG are based on the sum of all crack severity levels without the use of weight factors between the various severity levels.

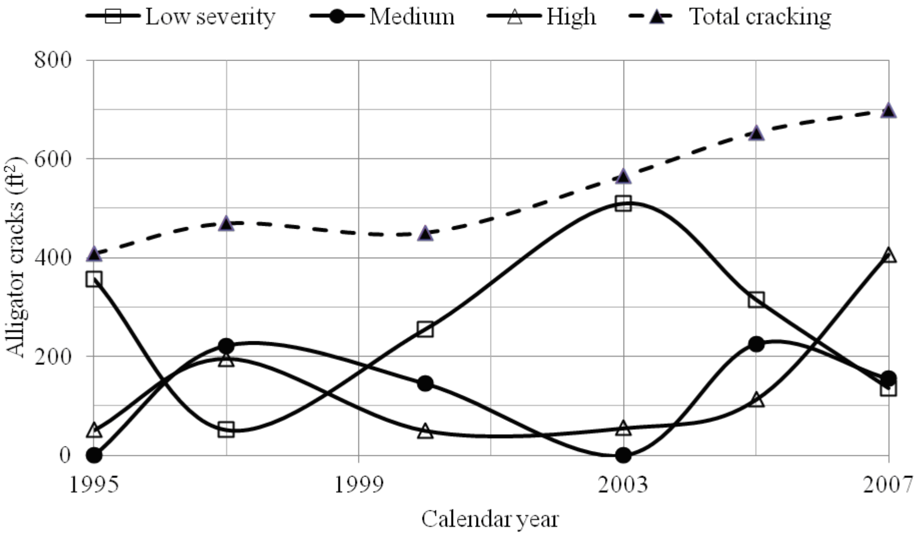


Figure 24
Low, medium, and high severity cracks and the total cracking as a function of time

The above observations apply to different degrees to the existing DOTD deduct points for random cracking and patching in flexible and composite pavements, and to transverse and longitudinal cracking and patching in concrete pavements. These deduct points are listed previously in Table 1 through Table 7 and shown in Figure 4 through Figure 10. It should be noted that the deduct points for low, medium, and high severity random cracking in flexible and composite pavements are the individual sum of all low, all medium, and all high severity longitudinal and transverse cracking in each pavement type. Thus, longitudinal and transverse cracks have the same impact (weight factor) on random cracking.

At the outset, it is important to note that, regardless of the values of the deduct points or their trends relative to the crack extent, they do not affect the decisions regarding the selection of the pavement project boundaries or the type of treatments. It is the trigger values that affect such decisions. For example, for a rating scale from 0 to 100, the deduct points for an X number of high severity transverse cracks in jointed concrete pavement could be assigned any number between 0 and 100, provided that the deduct points do not exceed 100 at the saturation level.

That is, the deduct points could be a linear or nonlinear function relative to the extent; further, the deduct points at the saturation level could be any number between 0 and 100. It is the trigger values that affect the decisions. Such trigger values must be assigned based on the magnitude of the actual pavement distress.

The above discussion is illustrated in Table 24 where four different deduct point systems are listed for each of the IRI, rut depths, and random cracking conditions. The trigger values for IRI, rut depth, and random cracking are based on 150 inch/mile, 0.375 in. of rut depth and 1600 ft. of linear cracking. As can be seen, the magnitude of the trigger values in terms of the deduct points changes from one deduct points system to the next, however, the trigger values are set at constant actual distress level. It is the amount of the distress not the deduct points that trigger certain types of pavement treatment. Nevertheless, the trigger values are discussed further in the following sections.

Saturation Levels for Pavement Patching and Cracking

Patching and crack saturation levels define:

1. The area of patching in square ft. (ft^2) at which the deduct points for patching do not increase as the patching area increases.
2. The extent of cracking in square foot (ft^2) or linear ft. (ft) at which the deduct points do not increase as the cracking extent increases.

The existing DOTD patching and crack saturation levels for each 1/10th mile pavement segment and for each pavement and crack type are listed in Table 25 below. In order to examine these saturation levels, the patching and cracking saturation levels listed in Table 25 were recalculated in terms of the percent by area or by length of the 1/10th mile pavement segment and the results are listed in Table 26. As can be seen from the percentages listed in Table 26, some of the patching and crack saturation levels need to be calibrated and/or redefined. For example, the existing patching saturation level is 100% of the surface area of 1/10th mile pavement segment. This is more or less replacement of the pavement along the entire 1/10th mile pavement segment. Likewise, the transverse crack saturation level is set at 500 cracks or at transverse crack spacing of 1 foot.

Table 24
Trigger values based on the actual distress and deduct points

IRI (inch/mile)								
IRI (in/mile)	Deduct point systems				Trigger value = 150 inch/mile			
					Trigger values based on deduct point systems			
	1	2	3	4	1	2	3	4
50	0	0	0	0				
100	10	5	2	1				
150	20	10	4	2	20	10	4	2
200	30	15	6	3				
250	40	20	8	4				
300	50	25	10	5				
350	60	30	12	6				
400	70	35	14	7				
450	80	40	16	8				
500	90	45	18	9				
Rut depth (in.)								
Rut depth (in.)	Deduct point systems				Trigger value = 0.375 in.			
					Trigger values based on deduct point systems			
	1	2	3	4	1	2	3	4
0.000	0	0	0	0				
0.125	0	10	5	2				
0.250	10	20	10	4				
0.375	20	30	15	6	20	30	15	6
0.500	30	40	20	8				
0.625	40	50	25	10				
0.750	50	60	30	12				
0.875	60	70	35	14				
1.000	70	80	40	16				
1.125	80	90	45	18				
1.250	90	100	50	20				
1.375	100	100	55	22				
Random cracking (linear ft.)								
Linear ft.	Deduct point systems				Trigger value = 1600 linear ft.			
					Trigger values based on deduct point systems			
	1	2	3	4	1	2	3	4
0	0.0	0.0	0.0	0.0				
30	1.0	10.0	5.0	20.0				
300	15.0	20.0	10.0	40.0				
1600	21.7	30.0	15.0	60.0	21.7	30.0	15.0	60.0
5000	30.0	40.0	20.0	80.0				
6000	32.7	50.0	25.0	100.0				
9999.99	32.7	60.0	30.0	100.0				

Based on the data listed in Table 26, the pavement patching and crack saturation levels for each 1/10th mile pavement segment and for each pavement type are redefined herein based on engineering judgment and the existing DOTD state-of-the-practice. The following patching and crack saturation levels are highly recommended:

1. For asphalt pavements, the existing alligator crack saturation level for flexible pavement of 3,168 ft^2, which is about 50% of the surface area of 1/10th mile pavement segment, appears to be reasonable and balanced.
2. For flexible and composite pavements, the recommended crack saturation level for transverse cracking is based on transverse crack spacing of about 6 ft. (half the lane width). This should yield 88 transverse cracks in 1/10th mile pavement segment. Thus the total transverse crack saturation level, assuming 12 ft. long cracks, is 1,056 ft.
3. For all pavement types, the recommended longitudinal crack saturation level is 200%. This is equivalent to two cracks along the entire 1/10th mile pavement segment. This recommendation would yield a longitudinal crack saturation level of 1,056 ft.

Table 25

Existing DOTD crack saturation level

Pavement type	Crack saturation level per crack type				Patching (ft^2)
	Alligator	Transverse	Longitudinal	Random	
Flexible	3,168	6,001	6,001	6,001	6,336
Composite	-	6,001	6,001	6,001	6,336
JCP	-	2,900	1,000	-	6,336
CRC	-	-	1,000	-	6,336

Table 26

Existing DOTD patching and cracking saturation level as percent of the 1/10th mile pavement segment

Pavement type	Crack saturation level per crack type					Patching percent by total area
	Alligator percent by area	Transverse		Longitudinal (percent by length)	Random (percent by length)	
		Number of crack	Crack spacing (ft)			
Flexible	50	500	1	1,137	1,137	100
Composite	-	500	1	1,137	1,137	100
		Number of crack	Percent of slab cracked	Longitudinal (percent by length)		-
JCP	-	242	733	189	-	100
CRC	-	-	-	189	-	100

For flexible and composite pavements, the recommended random cracking saturation level is the same as the longitudinal or the transverse cracking saturation level of 1,056 ft., since the DOTD defines random cracking as the sum of transverse and longitudinal cracking.

4. For JCP, the recommended transverse cracking saturation level is based on a maximum of 100% slab cracking. Assuming 16 ft slab length and one crack per slab, this would yield a maximum of 33 transverse cracks in 33 slabs. Assuming the length of each crack is 12 ft (the width of the slab), the recommended transverse crack saturation level is 396 ft.
5. For all pavement types, the existing 100% patching level implies that the entire 1/10th mile pavement segment has been patched. This implies the replacement of all slabs or the entire asphalt surface along the 1/10th mile pavement segment. This is considered replacement, not patching. The recommended patching saturation level is 50% patching or 3,168 ft^2.

The above recommendations regarding the patching and crack saturation levels are summarized in Table 27 and Table 28 below.

Once again, it is very important to note that the recommended saturation levels do not affect the trigger values for the various pavement treatments. The recommended patching and crack saturation levels are needed to develop continuous and consistent mathematical equations that can be easily implemented for the assignment of the deduct points. For each type of pavement distress and condition, the mathematical functions are presented in the next few subsections of this report.

Table 27
Recommended patching and cracking saturation levels

Pavement type	Crack saturation level per crack type				Patching (ft^2)
	Alligator (ft^2)	Transverse (ft.)	Longitudinal (ft.)	Random (ft.)	
Flexible	3,168	1,056	1,056	1,056	3,168
Composite	-	1,056	1,056	1,056	3,168
JCP	-	396	1,056	-	3,168
CRC	-	-	1,056	-	3,168

Table 28
Recommended patching and cracking saturation levels as percent of the pavement segment

Pavement type	Crack saturation level per crack type					Patching percent by total area
	Alligator percent by area	Transverse		Longitudinal percent by length	Random percent by length	
		Number of crack	Crack spacing (ft.)			
Flexible	50	88	6	200	200	50
Composite	-	88	6	200	200	50
		Number of crack	Percent of slab cracked	Longitudinal percent by length		
JCP	-	33	100	200	-	50
CRC	-	-		200	-	50

Calibration of Treatment Trigger Values

Pavement Distress and Cost Data

As stated earlier, the DOTD PMS state of the practice consists of the following information:

1. Measurements of the pavement condition data (IRI and rut depth) and the digitized data of the pavement surface images for distress.
2. Pre-established deduct points based on the type, severity, and extent of the pavement distresses, the measured pavement conditions, and road class.
3. Distress index based on the deduct points and a scale from 0 to 100 where 100 represent very good or excellent pavement conditions.
4. Trigger values based on road class and deduct points or index that would trigger certain types of pavement treatment.
5. Index reset values based on the type of pavement treatment and road class.

For most state highway agencies, including the DOTD, the deduct points and the trigger values systems were established before adequate time dependent pavement performance data were available in the PMS database. Given that this is no longer the case, the time dependent pavement performance data that are available in the PMS database could and should be used to calibrate the systems. Such calibration does not need to be undertaken for both the deduct points and the trigger values. The reason is that the assignment of the deduct point per unit of distress or rut depth could be arbitrary. The driving mechanism is the level and severity of the pavement distress or condition that would trigger an action or treatment. Thus, the trigger values must be based on the actual pavement distress and conditions. Recall Table 24, where four different deduct point systems were assigned to each of the IRI, rut depth and random cracking data. The trigger threshold values were based on the actual pavement distress and conditions as 150 inch/mile for IRI, 0.375 in. for rut depth, and 1,600 linear ft. of random cracking. It was found that the trigger values based on the deduct points were whatever the deduct points assigned to the actual distress trigger values. Therefore, only the trigger values based on actual distress are calibrated while slight modifications of the deduct points systems were recommended in the previous sections based on:

- The continuity of the deduct points over time and as functions of the measured time dependent pavement performance data (distress, IRI, and rut depths).
- The compatibility of the deduct points with the pavement performance prediction models, in general, and those embedded in the AASHTO Mechanistic-Empirical Pavement Design Guide (M-E PDG), in particular.

Ideally, the calibration of the trigger values should be based on two sets of data: the measured historical pavement performance data and the costs of the various pavement treatments.

Although the first set of data is available in details in the DOTD database, the cost data are available in a summary format only. Such data address the cost of the entire pavement project. That is, while the pavement distress and condition data are stored in the database for each 1/10th mile pavement segment, the cost data are available at the project level only. This is elaborated below.

For most pavement projects, the detailed time dependent pavement conditions and distress data along a given pavement project indicate that the before treatment (BT) pavement conditions and distress vary along the project from very good to fair and to poor as shown in Figure 25 through Figure 27. That is, the conditions of some 1/10th mile pavement segments are excellent to very good, fair for some others, and poor for yet other 1/10th mile pavement segments. Hence, it is highly likely that the cost per 1/10th mile pavement segment along the project is not uniform. For example, some or all of the 1/10th mile pavement segments in poor conditions may be subjected to pre-overlay repairs while those in fair and good conditions were not. Further, the pavement condition and distress data after treatment (AT) are also variables (Figure 25 to Figure 27) and thus the benefits of the applied treatment vary significantly from one 1/10th mile pavement segment to the next. Therefore, the calibration of the trigger values based on the real cost effectiveness of the treatment must include two sets of data:

- The pavement condition and distress before and after treatment. The data are needed to estimate the benefit of the treatment for each 1/10th mile pavement segment and the overall benefit for the project. Fortunately, such data are available in the DOTD database.
- The cost of the treatment for each 1/10th mile pavement segment along each pavement project. Recall that when a pavement project is subjected to a treatment, the index value of some of the 1/10th mile pavement segments are at the trigger values, and are higher or lower than the trigger values for some other segments (see Figure 25 through Figure 27). If the cost of the treatment is assumed to be equally distributed along all 1/10th mile pavement segments, then the cost is uniform and could be eliminated from the analysis. Unfortunately, such detailed cost data are not available in the DOTD database.

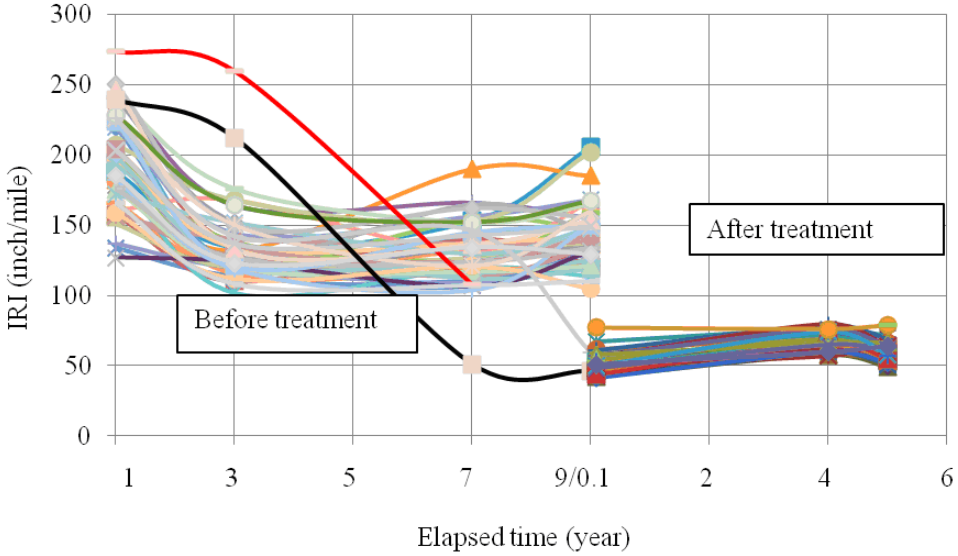


Figure 25

Measured IRI before and after treatment versus elapsed time, flexible pavement, arterial, overlay 2 to 4 in.es, LA 2, control section 037-02-1, 4.6 miles long

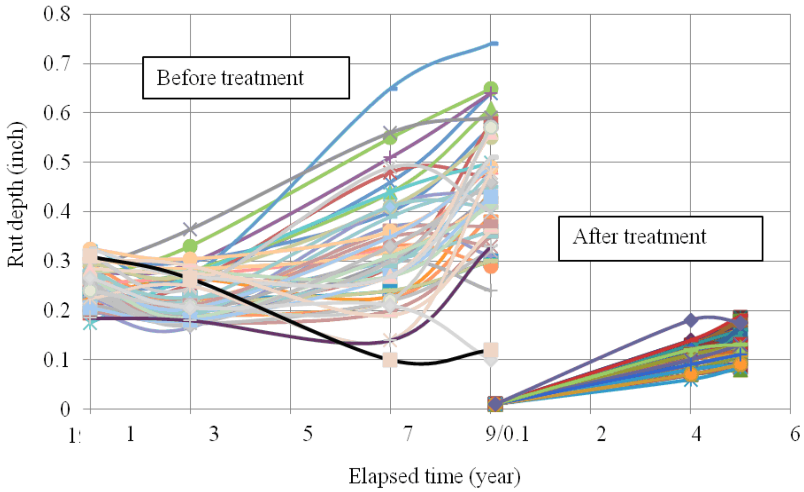


Figure 26
Measured rut depth before and after treatment versus elapsed time, flexible pavement, arterial, overlay 2 to 4 in.es, LA 2, control section 037-02-1, 4.6 miles long

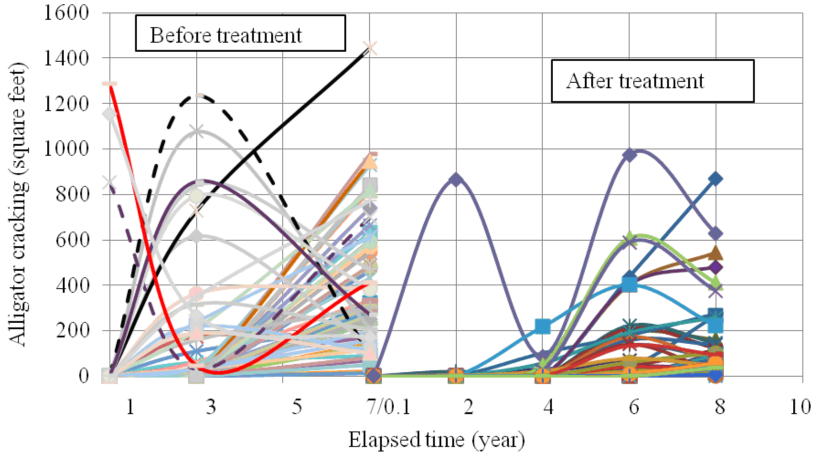


Figure 27
Estimated alligator cracking before and after treatment versus elapsed time, flexible pavement, collector, overlay 2 to 4 in.es, LA 10, CS 277-03-1, 6.4 miles long

One can argue that the cost effectiveness of a treatment for a given pavement project could be calculated based on the average pavement condition and distress before and after treatment and the average cost. Then the cost effectiveness of various projects can be compared to calibrate the trigger values. Although this is an ideal thought based on an ideal setting, the actual scenarios are different on both fronts, as enumerated below.

- For a given pavement treatment type, the data show that the before treatment distribution of the time dependent pavement condition and distress data along various projects are almost the same. Further, the average before and after treatment pavement conditions and distress along the various projects receiving the same treatment type are very similar. This is mainly due to the consistent state-of-the-practice regarding project and treatment selection. Hence the benefits of the various projects are more or less similar.
- The differences in the treatment costs between the various projects are mainly not, per se, treatment or trigger values related. They are functions of the detailed work plan such as 1- or 2- in. milling, pre-overly treatment, shoulder repair, shoulder and/or guard rail and safety improvement, equipment mobilization, and so forth. Indeed, for some pavement projects, the DOTD cost data indicate that the cost of 2-in. HMA overlay treatment per lane mile is substantially higher than the cost of 3.5-in. HMA overlay treatment per lane-mile.
- Table 29 through Table 31 and Figure 28 through Figure 33 depict the DOTD total cost and the average cost per lane-mile as a function of the project length. Once again, the differences in the cost per lane-mile are mainly due to different details of work for the various projects, as stated above.

The above scenarios indicate that the state of the cost data does not support the analysis of cost effectiveness by comparing the average benefits and costs of various projects along certain road class that received the same treatment type. Given the similarity of the average pavement performance between projects and the high variability of the pavement performance along each project, the cost effectiveness could be obtained within the projects when detailed cost data become available. To iterate, for a given road class and treatment type, cost-effective analyses of the treatment cannot be conducted at the network level. The reason is that the average time dependent before and after treatment pavement condition (IRI and rut depth) and distress (cracking) data for almost all projects receiving the same treatment type are almost the same.

Similarly, for a given treatment type and road class, the before and after treatment distribution of the pavement conditions and distress along one project is highly variable but more or less similar between projects receiving the same treatment type. This problem regarding the lack of detailed cost data is universal and mainly due to the existing state-of-the-practice of state highway agencies.

Nevertheless, given the lack of detailed cost data along the pavement projects, and the similarity of the before and after treatment pavement performance data between projects, the calibration of the trigger values was accomplished based on the DOTD pavement performance data before and after treatment and the benefits of each treated 1/10th mile pavement segment along the project. The procedures that were used to calculate the treatment benefits and to calibrate the trigger values are detailed in the next section of this report. For convenience, the procedures are divided into several related areas that cover a comprehensive pavement management system operation. Further, the procedures are written in user-friendly formats coupled, when possible, with examples using the DOTD PMS data. The procedures and the examples could be used in workshops or seminars for training and are mainly intended to assist the DOTD in their implementation.

Table 29
Cost data for asphalt pavement projects subjected to 2-in. and 3.5-in. HMA overlays, direction 1

Functional classification 3									
Asphalt Overlay thickness (in.)	District/ Region	Control Section	Route Number	Year	BLM	ELM	Project Length (lane-mile)	Project Cost ($)	Cost per lane-mile ($/lane-mile)
2	8	008-09-1	US 71	2002	0	8.8	8.8	2,381,057	270,575
	4	021-05-1	US 84	2002	0	0.3	0.3	35,253	117,510
	4	001-02-1	US 79	2002	0	4.4	4.4	1,119,255	254,376
	4	021-02-1	US 84	2003	0.7	7.1	6.4	1,165,501	182,110
	7	024-01-01	US 171	2003	2.1	5.6	3.5	919,523	262,721
	7	195-03-1	LA 385	2002	5.1	7.8	2.79	242,179	89,696
	8	008-08-1	US 71	2002	10.8	11.1	0.3	81,585	271,950
	Total						26.49	5,944,353	
	Average cost per lane mile ($)							224,400	
3.5	58	015-06-1	US 165	2002	0	3.3	3.3	799,451	242,258
	7	012-06-1	US 190	2002	0	5.1	5.1	1,056,872	207,230
	4	027-01-1	US 371	2002	0	7.1	7.1	1,759,948	247,880
	8	008-08-1	US 71	2002	0	4.6	4.6	1,200,621	261,005
	7	193-31-1	LA 397	2004	0	5.2	5.2	1,350,050	259,625
	2	855-07-1	LA 660	2005	0	4.8	4.8	1,823,432	379,882
	5	037-02-1	LA 2	2005	0	4.4	4.4	1,310,571	297,857
	61	426-02-1	LA 70	2002	0	0.8	0.8	161,488	201,860
	2	407-90-1	LA 308	2003	0	2.9	2.9	737,808	254,417
	8	008-07-1	US 71	2002	10.4	11.6	1.2	246,775	205,646
			Total				39.4	10,447,016	
			Average cost per lane mile					265,153	

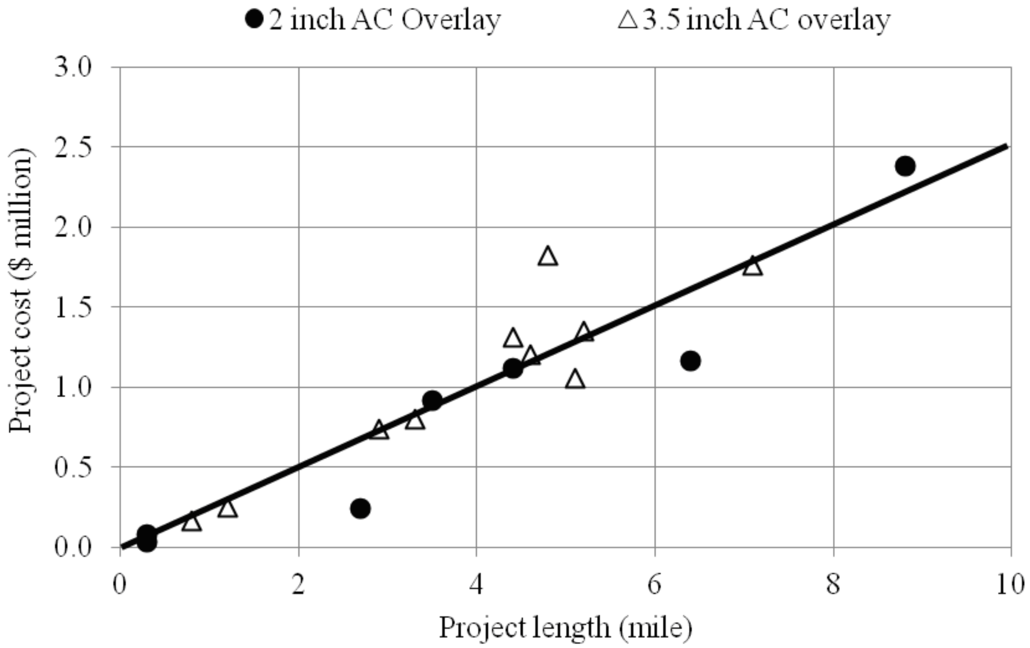


Figure 28

Cost of overlay as a function of flexible pavement project length, class 3

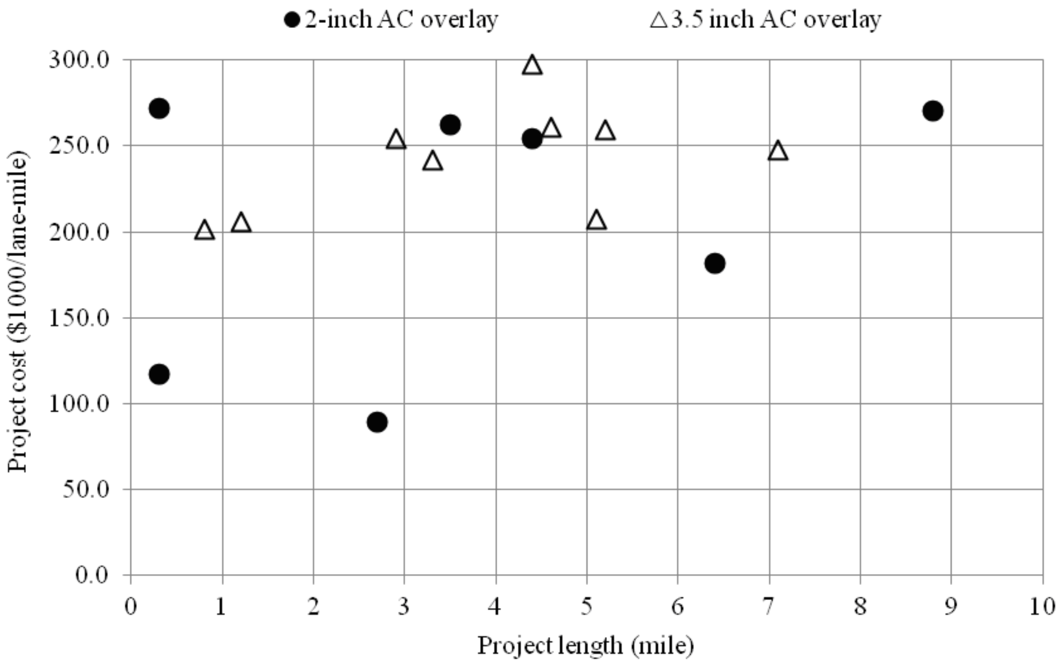


Figure 29

Cost per lane mile of various HMA overlay of flexible pavement projects, class 3

Table 30
Cost data for composite pavement projects subjected to 2-in. and 3.5-in. HMA overlays, direction 1

Functional classification 3									
Composite Overlay Thickness (in.)	District/ Region	Control Section	Route Number	Year	BMP	EMP	Project Length (lane-mile)	Project Cost ($)	Cost per lane-mile ($/lane-mile)
2	8	009-05-1	US 71	2003	0	5.4	5.4	2,216,531	410,469
	62	013-11-1	US 190	2002	0	3.2	3.2	1,124,552	351,423
	5	016-05-1	US 165	2004	12.3	16.2	3.9	1,351,387	346,509
	4	021-02-1	US 84	2002	0	0.4	0.4	79,474	198,685
	4	021-02-1	US 84	2003	0.5	0.7	0.2	36,830	184,150
	2	062-02-1	LA 23	2003	5.5	11.4	5.9	2,849,883	483,031
	62	256-30-1	LA 53	2001	0	1.7	1.7	452,331	266,077
							20.7	8,110,988	
	Average cost per lane mile ($)							391,835	
3.5	3	004-05-1	LA 182-E	2002	0	0.4	0.4	104,936	262,340
	3	004-05-1	LA 182-E	2002	9.4	11.8	2.4	608,629	253,595
	8	008-07-1	US 71	2002	10.4	11.6	1.2	276,775	230,646
	8	008-08-1	US 71	2002	0	4.6	4.6	1,200,621	261,005
	2	062-06-1	LA 23	2003	6.9	14.6	7.7	3,673,155	477,033
	2	064-02-1	LA 1	2001	0	6.4	6.4	2,624,120	410,019
	62	279-04-1	LA 60	2004	13.3	14	0.7	606,047	865,781
	62	279-04-1	LA 60	2004	14	16	2	1,518,953	759,477
	2	282-02-1	LA 48	2003	0	8.1	8.1	1,766,353	218,068
	5	834-13-1	LA 830-4	2004	0	0.2	0.2	74,534	372,668
	5	834-13-1	LA 830-4	2004	0.2	1.6	1.4	512,418	366,013
			Total				35.1	12,966,541	
			Average cost per lane mile ($)					369,417	

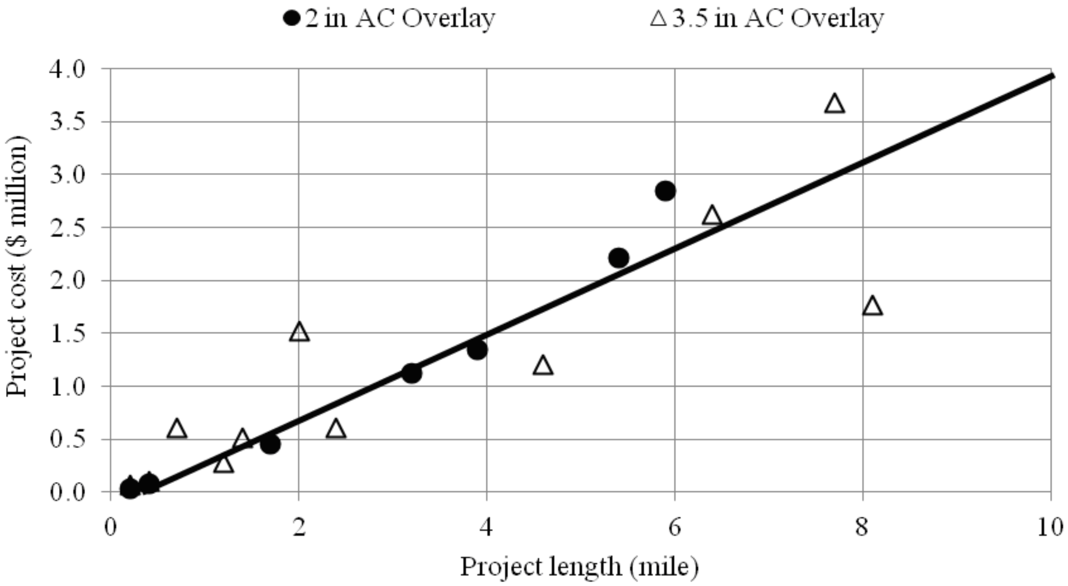


Figure 30

Cost of overlay as a function of composite pavement project length, class 3

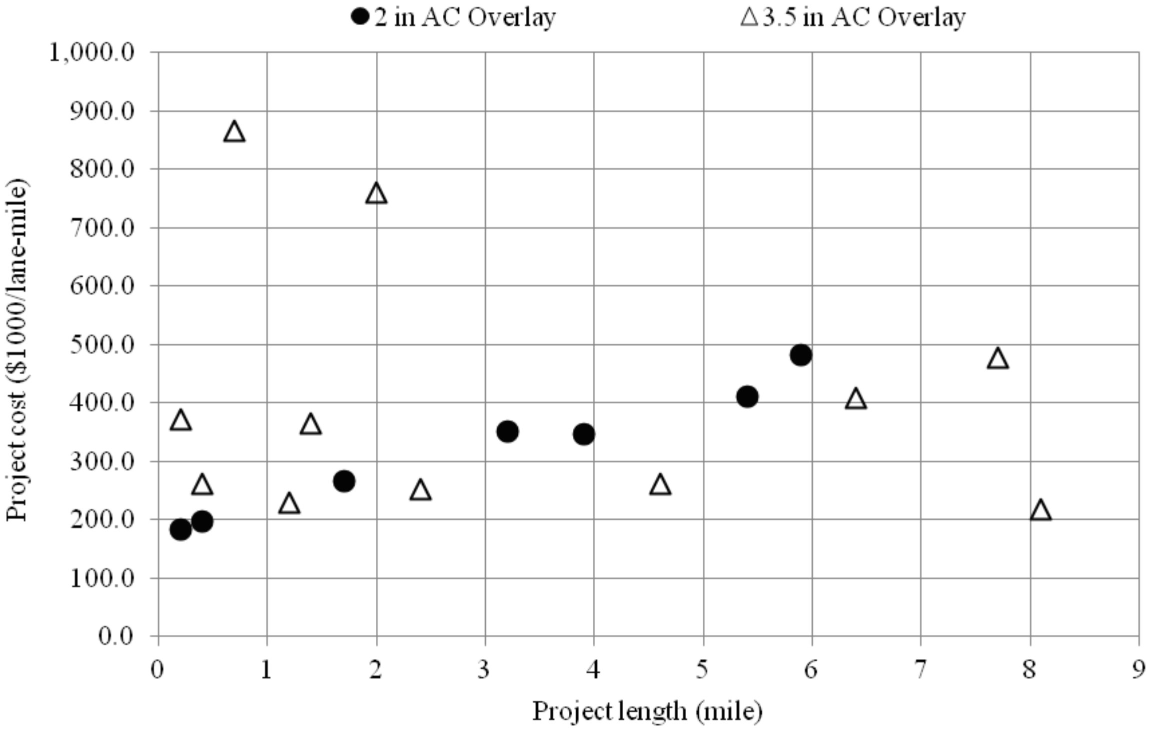


Figure 31

Cost per lane mile of various HMA overlay of composite pavement projects, class 3

Table 31
Cost data for JCP pavement projects subjected to 2-in. and 3.5-in. HMA overlays, direction 1

Functional classification 2									
JCP Overlay Thickness (in.)	District/ Region	Control Section	Route Number	Year	BLM	ELM	Project Length (lane-mile)	Project Cost ($)	Cost per lane-mile ($/lane-mile)
2	7	024-05-1	US 171	2004	2.8	3.7	0.9	264,860	294,289
	7	024-05-1	US 171	2004	4.2	6.3	2.1	594,463	283,078
	4	025-08-1	US 171	2002	15.3	15.6	0.3	75,794	252,648
							3.3	935,117	
								283,369	
3.5	7	003-08-1	US 90	2004	0	0.3	0.3	103,037	343,457
	3	424-04-1	US 90	2004	9.3	9.8	0.5	172,761	345,522
			Total				0.8	275,798	
			Average cost per lane mile					344,747	

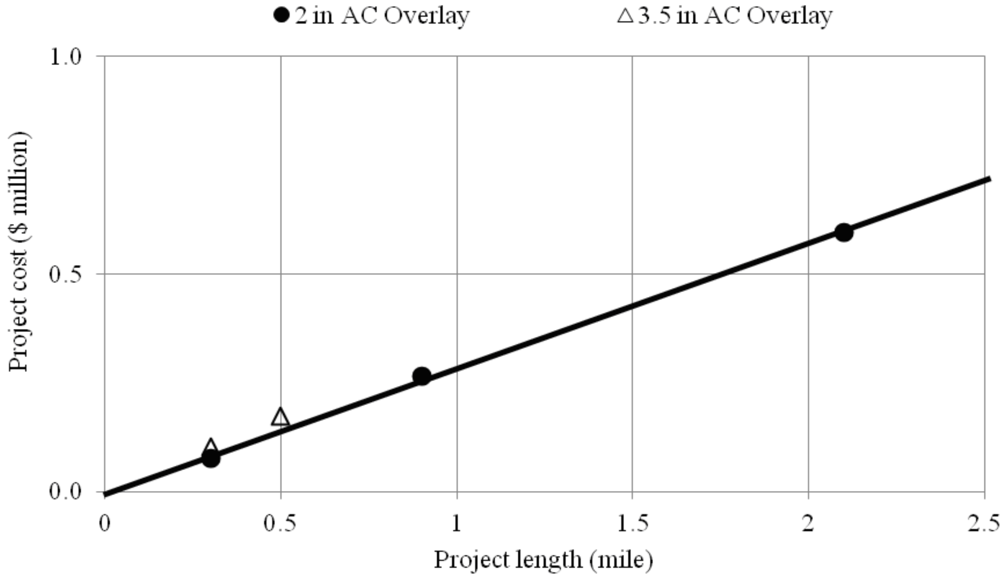


Figure 32

Cost of HMA overlay of JCP projects as a function of project length, class 2

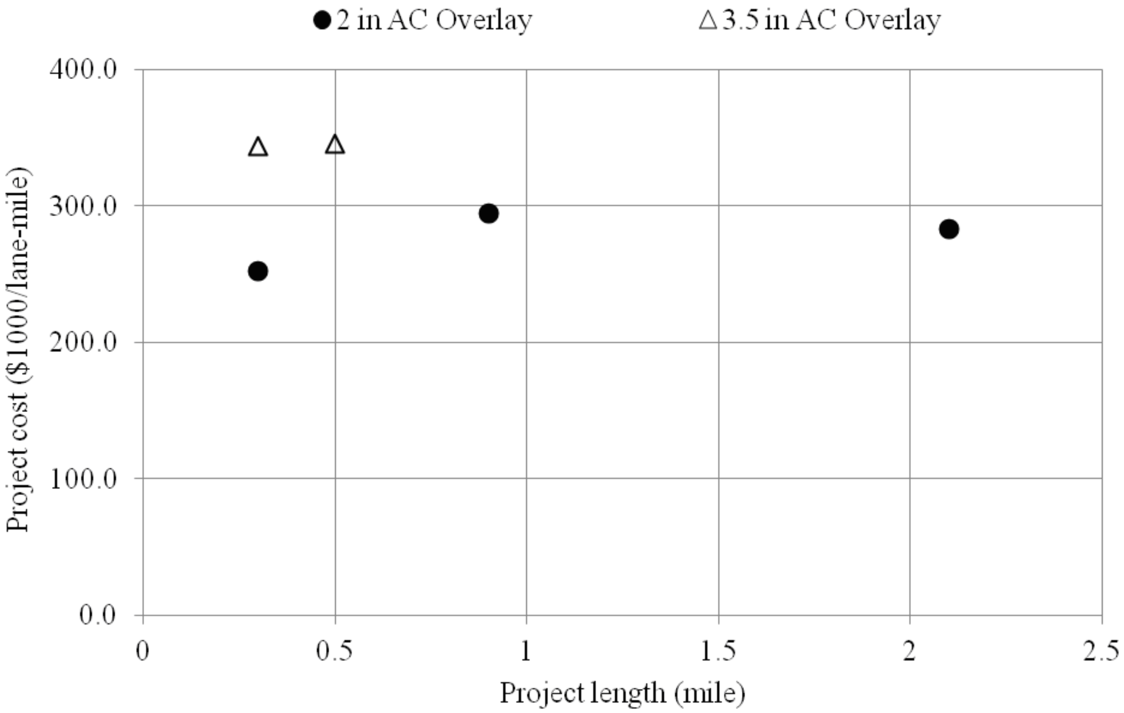


Figure 33

Cost per lane mile of five hot-mix asphalt overlay of JCP projects, class 2

Calibration of the DOTD Treatment Trigger Values

The procedures used to calculate the treatment benefits and to calibrate the DOTD trigger values are divided into various areas and detailed in this section. It is important to note that, if the distress or condition of some pavement segments has passed some safety threshold values (such as a blow up in concrete pavements, low friction, deep rutting in asphalt pavements, and so forth), corrective actions should be taken immediately or as soon as possible.

Area 1 - Data Mining. The PMS data mining could be accomplished in many ways depending on the capability of the database software, the users, and the availability of computers. Hence, the steps presented below are generic in nature and can be implemented by various users

Step 1.1 – Data: Obtain or download the required time series pavement condition and distress data from the DOTD database.

Step 1.2 – Data Format: Format or transform the data to excel spreadsheet or equivalent system to assist in the various calculations.

Step 1.3 – Data Search: Search the database and identify pavement projects that received, in the past, various treatment types.

Step 1.4 – Data Grouping: Group the projects per road class (interstate, arterial, collectors and locals) and per treatment type. Note that, some interactive database software allows the users to query on common denominators e.g., all projects along the Interstate or arterial network that received 3.5-in. HMA overlay, and so forth.

Area 2 – Data Acceptance Criteria. Unfortunately, for many reasons, some of the time series PMS data for some 1/10th mile pavement segments cannot be used in advanced analyses. Hence, the time series pavement condition and distress data of each 1/10th mile pavement segment of each identified pavement project in “Area-1” should be subjected to two acceptance criteria. The two criteria are addressed below:

Step 2.1 - First Acceptance Criterion “Three Data Points”: For each 1/10th mile pavement segment along each project, the database must have, as a minimum, three data points since the last treatment. If the pavement section was subjected to any treatment type in the past, then the database must have a minimum of three data points before treatment (BT) and three data points after treatment (AT). The reason is that pavement condition and distress are non-linear functions of time. The general and generic mathematical equations that are typically used to model the data are listed in equations (15) through (17).

$$\mathrm{IRI} = \alpha \exp(\beta t) \quad (15)$$

$$\mathrm{RD} = \gamma\, t^{\omega} \quad (16)$$

$$\mathrm{Crack} = \frac{k}{1 + \exp\left[-\theta\left(t - \mu\right)\right]} \quad (17)$$

Where, α, β, γ, ω, k, θ, and μ are regression parameters; IRI is the International Roughness Index in inch/mile; RD is rut depth; Crack is alligator, longitudinal, transverse, or random crack by length, area, or percentage; and is the elapsed time in years.

Any data set containing less than three data points should be either excluded from further analysis or subjected to one of the available data imputation procedures to impute the missing data points. Please note that, the accuracy of most available data imputation procedures is a function of the variability of the data over time. Given the variability of the DOTD data, data imputation is not recommended.

In certain scenarios, one other action could be taken to increase the number of available data points without affecting the outcome of the data modeling. For example, some initial pavement conditions and distress values immediately after certain treatment types are either measured as a part of the quality control processes or can be accurately assumed based on engineering judgment. In the first case, the quality control data could be requested, checked for accuracy and compatibility and integrated into the PMS database. In the second case, the data can be relatively accurately assumed. For example, immediately after an HMA overlay or mill and fill treatment, the rut depth is likely 0 and most, if not all, cracks are likely covered up and hence the rut depth and the length or area of cracks can be assumed 0 rut depth, crack length, or crack area at 0 time after construction are typically not accepted while modeling the data. Therefore, initial value of crack or rut depth at first month (0.083 year- after construction) is assumed.

Table 32 provides several recommended initial data reset for rutting, and four types of cracking that can be used while modeling the data or can be added to the PMS database.

Table 32

Recommended initial pavement condition and distress levels after certain treatments

Treatment type	Elapsed time (year)	Recommended initial after treatment conditions and distresses					
		Pavement condition		Pavement distress (cracking)			
		IRI (in/mile)	Rut depth (in.)	Transverse (ft)	Longitudinal (ft)	Alligator (ft^2)	Random (ft)
HMA overlays	0.083	*	0.01	0.01	0.01	0.01	0.01
Mill and fill	0.083	*	0.01	0.01	0.01	0.01	0.01
Reconstruction	0.083	*	0.01	0.01	0.01	0.01	0.01

The initial IRI data could be available as a part of the quality control for ride quality specification. In this case, the data should be requested and integrated into the PMS database. Alternatively, if desirable, one can use the maximum specified IRI value after construction.

Step 2.2 - Second Acceptance Criterion "Positive Slope:" For each 1/10th mile pavement segment along a given project, the time dependent pavement conditions and distress data that passed the first acceptance criteria should be subjected to the second acceptance criterion. First, check whether or not the time in the database is the elapsed time in years since the last treatment action. If not, calculate the elapsed time and store it in the database in the appropriate column or row (depending on the structure of the database). The elapsed time starts at 0.083 year immediately after the last treatment and it can be calculated as shown in the example below.

For a given pavement project, assume that two treatments were applied in 1999 and 2005 and the data collection cycles were made in 1999, 2001, 2003, 2005, 2007, 2009 and 2011. The four elapsed time values before the 2005 treatment are 0.083 year in 1999, and the differences between 2001 and 1999, 2003 and 1999, and 2005 and 1999. Whereas the four elapsed time values after the 2005 treatment are 0.083 year in 2005 and the differences between 2007 and 2005, 2009 and 2005, and between 2011 and 2005. Equation (18) states the mathematical formula for the calculation of the elapsed time after each treatment.

$$\mathrm{ET}_1 = 0.083\,\mathrm{year} \tag{18}$$

$$\mathrm{ETi} = \mathrm{Data\ collection\ year}_i - \mathrm{Treatment\ year} \tag{19}$$

Where, the data collection year "i" is the calendar year of data collection cycle "i" after treatment. Treatment year is the calendar year of the treatment.

The use of elapsed time and its limitation to 0.083 year is due to the following reasons:

- Some mathematical models do not accept 0 time and/or 0 distress values.
- If the calendar year is used and if the data collection cycle happened in 2001, the best curve fitting technique assumes that the 2001 measured pavement condition and distress data happened 2001 years after the completion of the last treatment.

Alternatively, if the pavement surface age (SA) is available in the PMS database, it could be used as the elapsed time. It should be noted that, in some agencies or for some pavement projects, the SA data may not be included in the PMS database. The pavement SA data could be found in the pavement maintenance, preservation, and/or rehabilitation records. Nevertheless, the pavement SA is the difference between the calendar year of the data collection cycle in question and the year of completion of the last treatment, preservation, and/or rehabilitation actions. If the year of completion is not known, the SA could be estimated from experience. Otherwise, it could be ignored and the elapsed time could be set at 0.083 year for the first data collection cycle and calculated for the other data collection cycles using equation (19). It should be noted that inaccurate pavement SA causes error in the performance model and it physically implies that the first measured pavement condition and/or distress data occurred at 0.083 year.

The procedure for the second acceptance criteria varies and depends on the following scenarios of the available time series pavement conditions and distress data:

1. For the period during which time series pavement condition and distress data are available, no treatment was performed. That is, the entire time series data set was collected after the completion of a treatment. In this scenario, model the entire data set as a function of the elapsed time (the pavement surface age) using the proper mathematical function [equations (15) through (17)]. Examine the regression parameters of the function to determine whether or not the slope of the function is positive. Positive slope is required to be able to model the pavement rate of deterioration. Negative slope implies self-healing without the application of any treatment. Negative slope could be caused by data inaccuracy, equipment malfunction, and/or human errors such as storing the data at the wrong reference location. Exclude all 1/10th mile pavement segments showing negative slopes from further analysis.
2. For the period during which time series pavement condition and distress data are available, a treatment was performed at a certain year. In this case, if the pavement performance data contain minimum of three data points before treatment (BT) and three data points after treatment (AT), separate the data accordingly. Model the BT and the AT data using the proper mathematical function and obtain two sets of regression parameters; BT and AT (the AT elapsed time should be reset to 0.083 year at the time of the treatment). For any 1/10th

mile pavement segments where the BT and AT slopes are negative, the 1/10th mile pavement segment should be excluded from further analysis. Otherwise, if either the BT or the AT data set shows positive slope, that data set could be used to determine the pavement rate of deterioration and the RSL before or after treatment.

If the data of a 1/10th mile pavement segment fails one or both acceptance criteria (no three data points and/or negative slope), it should be excluded from any further analysis. The number or the percent of the failed pavement segments in each acceptance criterion can be used to improve the data collection process, data accuracy, and the quality control procedures. In general, the percent of the 1/10th mile pavement segments that passes the first acceptance criterion is much higher than that of the second criterion. In addition, as expected, sensor collected data (IRI and rut depth) have higher percent acceptance of both criteria than the cracking data. Table 33 provides a list of the percentages of the BT and AT data of the 1/10th mile pavement segments that passed each of the two acceptance criteria in the state of Louisiana. For comparison purpose, the percent data acceptance for the states of Colorado and Washington are listed in Table 34 and Table 35 respectively.

The data in Table 33 through Table 35 indicate that, for most cases, the PMS databases of the three agencies contain a minimum of three data points before and three data points after treatment. Occasionally, for certain data collection cycles, the data along one or two 1/10th mile pavement segments are not recorded. This could be due to malfunctioning of sensors, lane closure during data collection, or simply the sensor data were not saved. The percent of the data passed the second acceptance criterion however, varies from 16% to 100%. It can be seen that, in general, much more sensor data (IRI and rut depth) passed the second acceptance criterion than the cracking data. Once again, this was expected due mainly to the image digitization processes.

If the percent of the data passing the second criterion is consistently low, it is recommended that the data collection procedures (especially image based data) be reviewed. Perhaps, the data digitizers should receive further training and/or the quality control/quality assurance processes should be reviewed and improved.

Table 33
Percentage of the before and after treatment data passed the acceptance criteria, Louisiana

TT	BT, AT, & the number of 1/10th mile pavement segments	The percent of 1/10th mile pavement segments passing each acceptance criterion for each condition and distress type, and the number of 1/10th mile pavement segments accepted and available in the database										Number of 1/10th mile pavement segments accepted[3]
		IRI		RD		AC		LC		TC		
		1	2	1	2	1	2	1	2	1	2	
A	BT (%)	88.8	63.7	95.4	47.7	95.4	61.8	99.8	16.2	99.8	31.6	---
	AT (%)	94.5	85.7	97.9	100	99.6	71.9	99.6	74.7	99.6	84.4	
	Accepted[1]	219		224		202		71		134		439
	Available[2]	526		526		526		526		526		526
B	BT (%)	97.5	69.2	97.5	52.4	97.8	64.0	98.7	31.1	98.7	47.3	---
	AT (%)	94.5	87.8	99.4	100	99.8	71.5	99.8	72.2	99.8	79.5	
	Accepted[1]	1,416		1,242		1,199		595		984		2,279
	Available[2]	2,511		2,511		2,511		2,511		2,511		2,511
C	BT (%)	95.5	61.6	96.1	67.7	96.1	91.4	96.7	48.8	96.7	49.1	---
	AT (%)	94.1	78.7	81.2	63.6	99.8	74.4	99.8	71.8	99.8	79.9	
	Accepted[1]	1,089		574		1,605		772		819		2,131
	Available[2]	2,421		2,421		2,421		2,421		2,421		2,421
D	BT (%)	98.8	60.5	67.9	75.8	99.0	87.2	99.5	35.3	99.8	24.2	---
	AT (%)	97.8	88.9	71.9	54.3	99.8	51.6	99.8	58.5	99.8	65.7	
	Accepted[1]	206		43		177		61		44		316
	Available[2]	405		405		405		405		405		405
E	BT (%)	92.1	64.1	95.3	70.7	97.0	75.1	97.5	25.5	97.5	40.6	---
	AT (%)	90.1	87.1	84.1	100	97.0	58.9	97.0	81.9	97.0	88.2	
	Accepted[1]	163		191		146		80		135		311
	Available[2]	365		365		365		365		365		365
F	BT (%)	96.6	74.4	91.4	77.8	92.0	80.3	99.4	33.3	99.4	40.5	---
	AT (%)	92.7	82.8	99.3	100	99.6	56.4	99.6	69.8	99.6	74.5	
	Accepted[1]	735		957		605		286		396		1,280
	Available[2]	1,390		1,390		1,390		1,390		1,390		1,390

TT = Treatment type:

A = Thin HMA overlay of asphalt surfaced pavements; B = Thick HMA overlay of asphalt surfaced pavements; C = Single chipseal ; D = Double chipseal ; E = Thin mill and fill of asphalt surfaced pavements; F = Thick mill and fill of asphalt surfaced pavements.

RD = Rut Depth; AC = Alligator Cracks; LC = Longitudinal Cracks; TC = Transverse Cracks.

1 = acceptance criterion 1; 2 = acceptance criterion 2

[1] Number of 1/10th mile pavement segments accepted

[2] Number of 1/10th mile pavement segments available in each pavement condition and distress type

[3] If a pavement segment is accepted in 1 or more pavement condition or distress type it is counted one time only.

Table 34
The percent of the before and after treatment data passed the two acceptance criteria, Colorado

TT	BT, AT, & the number of 1/10th mile pavement segments	The percent of 1/10th mile pavement segments passing each acceptance criterion for each condition and distress type, and the number of 1/10th mile pavement segments accepted and available in the database										Number of 1/10th mile pavement segments accepted[3]
		IRI		RD		AC		LC		TC		
		1	2	1	2	1	2	1	2	1	2	
A	BT (%)	99.6	82.3	99.6	62.3	99.6	78.5	99.6	68.2	85.9	77.5	---
	AT (%)	98.4	72.6	99.7	96.2	98.4	69.4	98.4	58.5	98.4	63.7	
	Accepted[1]	557		559		506		384		385		878
	Available[2]	968		968		968		968		968		968
B	BT (%)	---										
	AT (%)											
	Accepted[1]											
	Available[2]											
C	BT (%)	98.5	60.5	98.5	39.2	98.5	62.9	98.5	67.5	77.7	78.9	---
	AT (%)	94.5	77.3	94.5	36.9	94.5	75.2	94.4	76.6	94.4	82.1	
	Accepted[1]	2,281		399		2,228		2,440		2,163		4,033
	Available[2]	4,958		4,958		4,958		4,958		4,958		4,958
D	BT (%)	---										
	AT (%)											
	Accepted[1]											
	Available[2]											
E	BT (%)	100	73.6	100	81.3	100	84.6	100	61.5	100	60.4	---
	AT (%)	73.6	69.2	100	100	73.6	94.5	73.6	92.3	73.6	80.2	
	Accepted[1]	28		74		49		38		24		83
	Available[2]	91		91		91		91		91		91
F	BT (%)	---										
	AT (%)											
	Accepted[1]											
	Available[2]											

TT = Treatment type:
A = Thin HMA overlay of asphalt surfaced pavements; B = Thick HMA overlay of asphalt surfaced pavements; C = Single chipseal ; D = Double chipseal ; E = Thin mill and fill of asphalt surfaced pavements; F = Thick mill and fill of asphalt surfaced pavements.
RD = Rut Depth; AC = Alligator Cracks; LC = Longitudinal Cracks; TC = Transverse Cracks.
1 = acceptance criterion 1; 2 = acceptance criterion 2

[1] Number of 1/10th mile pavement segments accepted

[2] Number of 1/10th mile pavement segments available in each pavement condition and distress type

[3] If a pavement segment is accepted in 1 or more pavement condition or distress type it is counted one time only.

Table 35
The percent of the before and after treatment data passed the two acceptance criteria, Washington

TT	BT, AT, & the number of 1/10th mile pavement segments	The percent of 1/10th mile pavement segments passing each acceptance criterion for each condition and distress type, and the number of 1/10th mile pavement segments accepted and available in the database										Number of 1/10th mile pavement segments accepted[3]
		IRI		RD		AC		LC		TC		
		1	2	1	2	1	2	1	2	1	2	
A	BT (%)	50.6	74.3	50.6	83.4	100	85.1	100	55.5	100	74.3	---
	AT (%)	99.1	74.4	100	99.7	100	98.0	100	87.2	100	97.7	
	Accepted[1]	349		709		1,746		1,000		1,538		2,059
	Available[2]	2,100		2,100		2,100		2,100		2,100		2,100
B	BT (%)	37.8	65.6	37.9	88.4	100	87.3	100	79.6	100	49.5	---
	AT (%)	100	80.2	100	99.8	100	99.1	100	84.5	100	96.6	
	Accepted[1]	10		122		403		310		220		461
	Available[2]	465		465		465		465		465		465
C	BT (%)	100	82.4	100	64.2	100	92.7	100	73.5	100	99.5	---
	AT (%)	100	33.3	100	28.4	100	83.3	100	73.5	100	95.1	
	Accepted[1]	52		38		156		111		194		203
	Available[2]	204		204		204		204		204		204
D	BT (%)	---										
	AT (%)											
	Accepted[1]											
	Available[2]											
E	BT (%)	88.3	42.4	88.3	81.8	96.1	94.3	96.1	43.3	96.1	67.9	---
	AT (%)	83.3	83.7	100	99.1	100	96.7	100	88.2	100	97.0	
	Accepted[1]	123		701		886		357		633		946
	Available[2]	1,013		1,013		1,013		1,013		1,013		1,013
F	BT (%)	---										
	AT (%)											
	Accepted[1]											
	Available[2]											

TT = Treatment type:
A = Thin HMA overlay of asphalt surfaced pavements; B = Thick HMA overlay of asphalt surfaced pavements; C = Single chipseal ; D = Double chipseal ; E = Thin mill and fill of asphalt surfaced pavements; F = Thick mill and fill of asphalt surfaced pavements.
RD = Rut Depth; AC = Alligator Cracks; LC = Longitudinal Cracks; TC = Transverse Cracks.
1 = First acceptance criterion; 2 = Second acceptance criterion

[1] Number of 1/10th mile pavement segments accepted

[2] Number of 1/10th mile pavement segments available in each pavement condition and distress type

[3] If a pavement segment is accepted in 1 or more pavement condition or distress type it is counted one time only.

Area 3 - Data Analysis Steps – Treatment Transition Matrices (T2M). For each pavement project and for each 1/10th mile pavement segment along the project, the time dependent pavement condition and distress data that passed the two acceptance criteria could be subjected to various analyses and the results could be displayed in a special format called herein treatment transition matrices (T^2M). The analyses procedure for each step leading to the T^2M is detailed below.

Step 3.1 - Data Analysis – Remaining Service Life – The remaining service life (RSL) of a given pavement segment can be calculated using equation (20).

$$0 \leq [\mathrm{RSL} = \mathrm{t} - \mathrm{SA}] \leq [\mathrm{DSL} - \mathrm{SA}] \tag{20}$$

Where, RSL equals remaining service life relative to a given distress type (year); t equals the elapsed time from the last treatment to the time when the threshold value of the distress in question is reached (year), see Table 36; SA equals the pavement surface age or the elapsed time, which is the time in years since the last treatment (year); DSL equals the assumed pavement design service life or the average pavement treatment life (year)

The limitations on the calculated value of RSL in equation (20) are based on the following practical experience and data observations *[1]*.

1. The minimum RSL value is limited to zero; no negative values. The reason is that the RSL represents the condition state of the pavement structure. Zero RSL values imply that the users are driving on pavement sections having substandard condition states. The implication of negative RSL values is exactly the same as the zero RSL value. The extra information in the negative RSL value is the extended time in years during which the users are driving on pavement segments having substandard conditions.

2. The upper limit on RSL is the design or the treatment life of the pavement section minus its surface age. This limit is practical because, for a new pavement structure or for some years immediately after treatment, the pavement surface will show little to no deterioration for few years. Mathematically, the RSL value would be very large. Thus, the upper limitation of design or treatment life solves the problem. It is highly likely that the upper limitation is not needed for older pavement sections showing some signs of deterioration.

The lower and upper limits of the RSL values are parallel to the lower and upper limits of the deduct point system. The lowest deduct point is zero and the upper is a number between zero and 100. Likewise, the two RSL limits are parallel to the two limits of the AASHTO pavement serviceability index (PSI) of that after construction and the terminal of 2.5 for Interstates. The RSL of a given pavement network can be calculated as the weighted average RSL of the "n" pavement segments within the network using equation (21) *[1]*.

Table 36

Generic pavement condition and distress models and the calculations of the time when the pavement conditions reach the pre-specified threshold value, the pavement rate of deterioration, and the area under the pavement performance curve

Pavement condition/ distress type	International Roughness Index (IRI) (inch/mile or m/km)	Rut depth (RD) (in. or mm)	Cracking (length, area, or percent)
Model form	Exponential	Power	Logistic (S-shaped)
Generic equation	$\mathrm{IRI} = \alpha \exp(\beta t)$	$\mathrm{RD} = \gamma\, t^{\omega}$	$\mathrm{Crack} = \frac{k}{1 + \exp[-\theta(t - \mu)]}$
Time when a threshold value is reached	$t = \frac{\ln\left(\frac{\mathrm{Threshold}_{\mathrm{IRI}}}{\alpha}\right)}{\beta}$	$t = \exp\left[\frac{\ln\left(\frac{\mathrm{Threshold}_{\mathrm{RD}}}{\gamma}\right)}{\omega}\right]$	$t = -\left[\frac{\log\left(\frac{k}{\mathrm{Threshold}_{\mathrm{Crack}}} - 1\right) - \theta * \mu}{\theta}\right]$
Derivative (rate of deterioration)	$\frac{d\,\mathrm{IRI}}{dt} = \alpha\, \beta \exp(\beta t)$	$\frac{d\,\mathrm{RD}}{dt} = \gamma \omega t^{(\omega - 1)}$	$\frac{d\,\mathrm{Crack}}{dt} = -\frac{k * \theta * \exp(\theta(t + \mu))}{(\exp(\theta t) + \exp(\theta \mu))^{2}}$
Integral (area)	$A_{\mathrm{IRI}} = \int_{t_1}^{t_2} = \left(\frac{\alpha}{\beta}\right)\exp(\beta t)$	$A_{\mathrm{RD}} = \int_{t_1}^{t_2} = \frac{\gamma\, t^{(\omega+1)}}{(\omega + 1)}$	$A_{\mathrm{Crack}} = \int_{t_1}^{t_2} = k\left[\mu - \frac{\log(\exp(\theta(\mu - t)) + 1)}{\theta}\right]$
Where, α, β, γ, ω, k, θ, and μ are regression parameters, RD is rut depth, Crack is alligator, longitudinal, or transverse crack length, area or percent, t is the elapsed time in years, and Threshold is the pre-specified condition level indicating zero serviceability for any given pavement condition or distress type.			

$$\mathrm{RSL}_{(\mathrm{network})}=\frac{\sum_{i=1}^{n}(\mathrm{RSL}_i)(\mathrm{SL}_i)}{\sum_{i=1}^{n}\mathrm{SL}_i} \qquad (21)$$

Where, RSL(network) equals the remaining service life of a road network (year); RSLi equals the remaining service life I (2, 3, 5 or x years) of pavement section length I along the network; SLi equals the cumulative length of all 1/10th mile pavement segments having the same RSLi value.

The weighted average RSL value of the pavement network obtained from equation (1) can be used to estimate the impact of the available budget on the conditions of the pavement network.

Alternate to the calculation of the RSL values using the time dependent pavement condition and distress data, the RSL could be calculated using either the time dependent deduct points system or the time dependent distress index values. For the deduct points system, maximum deduct point threshold value for each pavement distress and condition should be specified. Likewise, for the distress index, the minimum distress index value for each pavement distress and condition should be established. After establishing the threshold values, the time dependent deduct points or the time dependent distress index could be used to calculate the time from construction or treatment year to the year when the pavement section reaches the pre-specified threshold value of deduct points or distress index.

Step 3.2 – Controlling RSL Value - After calculating one RSL value for each 1/10th mile pavement segment and for each condition and distress type, select the lowest RSL value as the controlling RSL for that segment. Establish various condition states where each state is based on a range of RSL values. It is recommended that five condition states (CS) be adopted as follows:

- CS 1 (CS-1) where the RSL value ranges from 0.0 to 2 years, (poor).
- CS 2 (CS-2) where the RSL value ranges from 3 to 5 years, (fair).
- CS 3 (CS-3) where the RSL value ranges from 6 to 10 years, (good).
- CS 4 (CS-4) where the RSL value ranges from 11 to 15 years, (very good).
- CS 5 (CS-5) where the RSL value ranges from 16 to 25 years, (excellent).

The reason the RSL ranges increase with increasing RSL values is that the accuracy of the calculated RSL decreases as the condition and distress data is predicted for the more distant future.

For each pavement condition and distress type and for each 1/10th mile pavement segment passed the two data acceptance criteria; the calculation of the RSL is based on the following four possible data scenarios:

Scenario 1 – All pavement segments that were not treated in the past (do-nothing pavement segments). For each segment in this group, use the entire time series data of each condition and distress data type, the proper regression parameters from the best fit model from acceptance criterion 2, and the established threshold value to calculate one RSL value per each condition and distress type. This is shown schematically in Figure 34 for the number of high severity transverse cracks.

Scenario 2 – All pavement segments that were treated in the past and the data base contains adequate time series data before and after treatment. For each pavement segment in this group, use the before treatment time series of each pavement condition and distress data type, the proper regression parameters from the best fit model from acceptance criterion 2, and the established threshold value to calculate one before treatment RSL value per each condition and distress type as shown in Figure 35. Repeat the same procedure using the after treatment time series data also shown in Figure 35. Two very important points should be noted relative to Figure 35.

- The elapsed time, which is the same as the pavement surface age, on the horizontal axis has two starting points at 0.083 year after treatment; one for the before treatment data and the other for the after treatment data. Stated differently, the time clock or the pavement surface age starts at the treatment time.
- For each pavement condition and distress type, two after treatment RSL values can be calculated; one is the RSL immediately after treatment, which is labeled "AT RSL" in Figure 35. The other is the RSL value after the last data collection cycle, which is labeled RSL in the figure. The difference between the AT RSL and the RSL is the pavement surface age of 8 years since the last treatment action as shown in Figure 35.

Scenario 3 – All pavement segments that were treated in the past and the database contains adequate time series data before treatment only (three or more data points).

For each pavement segment in this group, use the before treatment time series of each condition and distress data type, the proper regression parameters from the best fit model from acceptance criterion 2, and the established threshold value to calculate one before treatment RSL value per each condition and distress type as shown in Figure 44. The RSL values for these pavement segments could be used, among other things, in the analysis of the average longevity of the pavement network.

Scenario 4 - All pavement segments that were treated in the past and the database contains adequate time series data after treatment only. For each pavement segment in this group, use the after treatment time series of each condition and distress data type, the proper regression parameters from the best fit model, acceptance criterion 2, and the established threshold value to calculate one after treatment RSL value per each condition and distress type as shown in Figure 37.

It should be noted that for each one of the four scenarios, the RSL could be calculated using either the time series pavement condition and distress data, the time and distress dependent deduct points, each of the time dependent individual distress indices, or the time dependent combined distress indices. However, it is strongly recommended that one RSL value be calculated using each pavement condition and distress type or each individual distress index (no combined index). The main reason is that the combined index may yield acceptable index value and yet one or more of the pavement condition or distresses are worse than the acceptable threshold value.

After calculating one RSL value for each pavement condition and distress type of each 1/10th mile pavement segment, the lowest of the RSL values should be assigned to that segment. Such minimum RSL represents the number of years from the last data collection year where the pavement should be treated. The calculated RSL values could be subjected to further analysis at the network, project, and treatment type levels. These are presented in the next step.

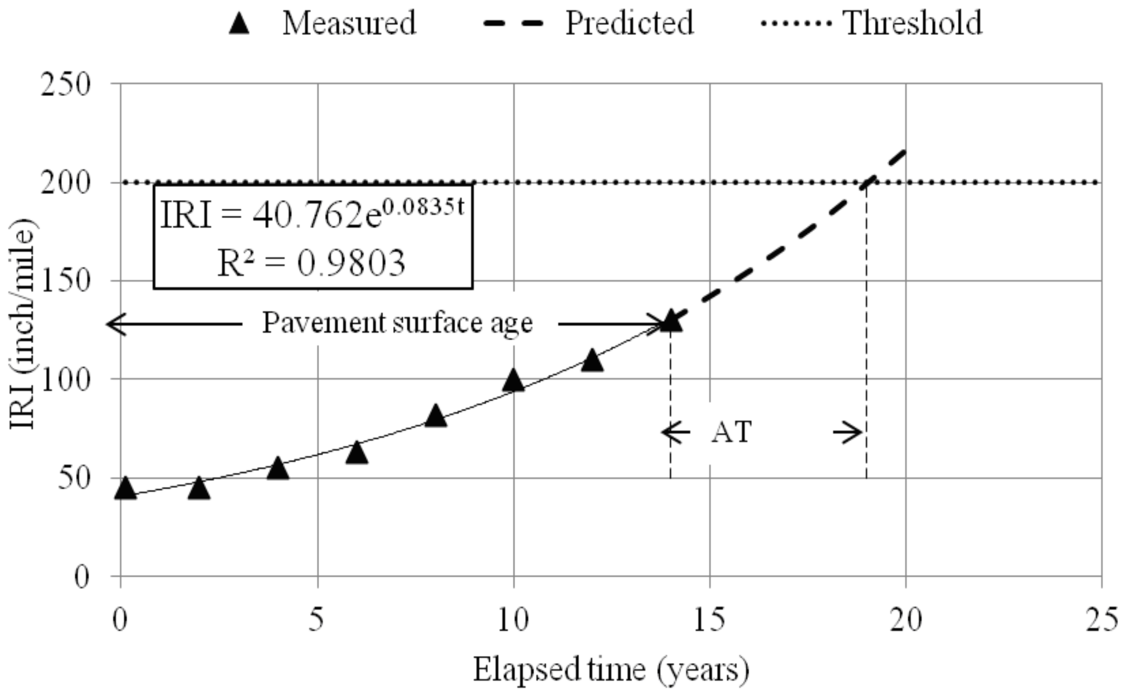


Figure 34
Calculation of RSL based on the elapsed time since last action

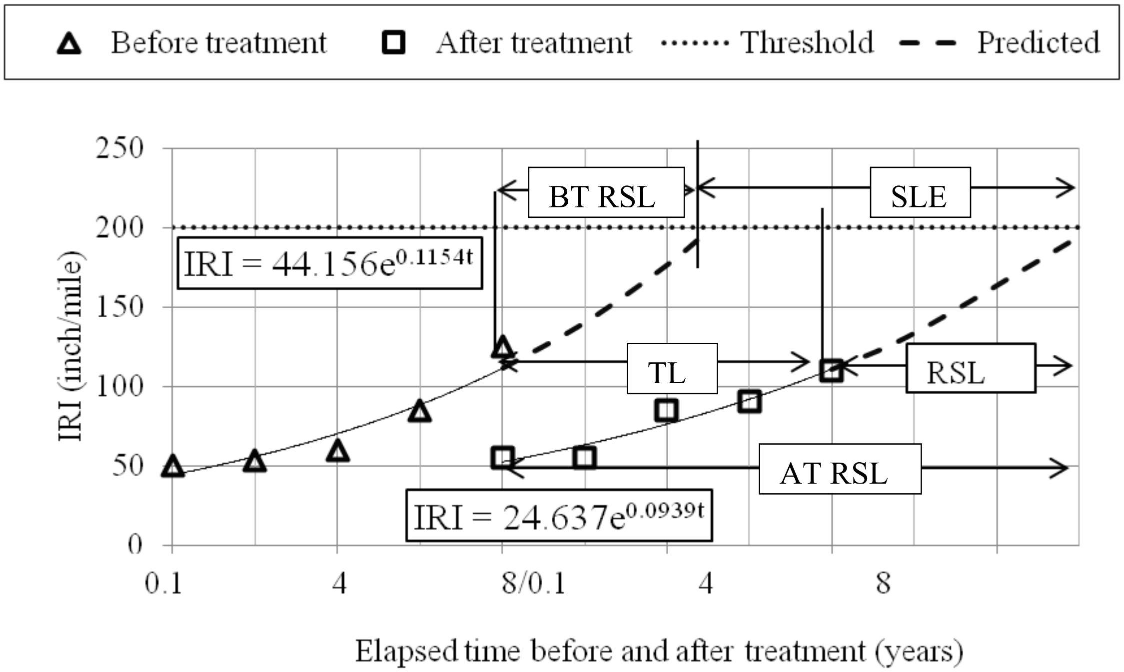


Figure 35
Before and after treatment RSL, service life extension (SLE), and treatment life (TL)

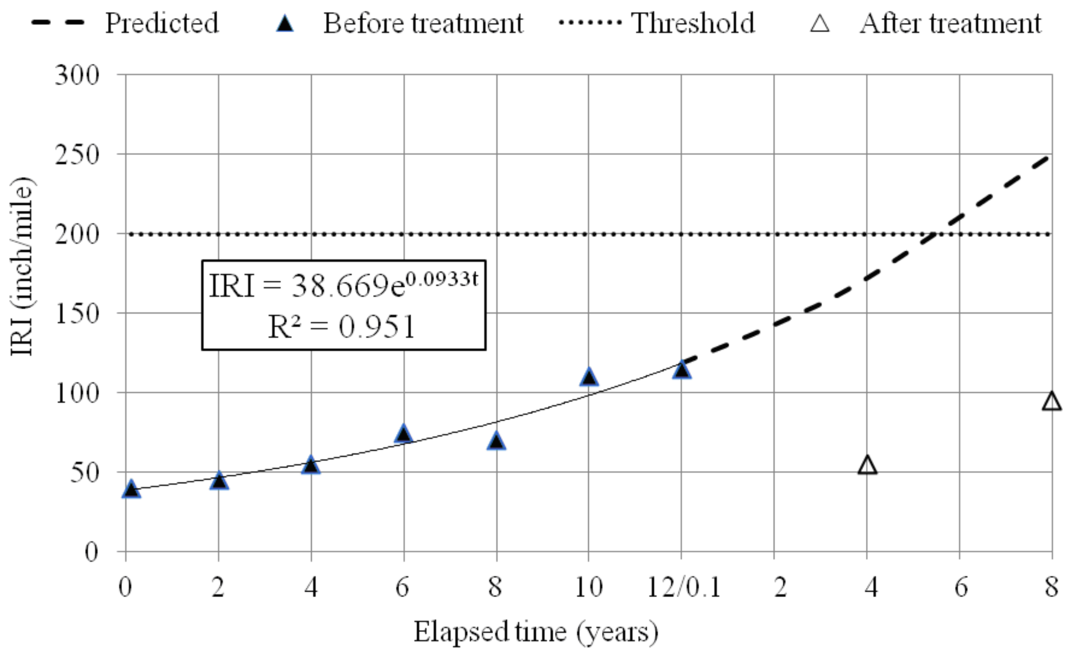


Figure 36

Calculation of RSL; adequate before and insufficient after treatment data

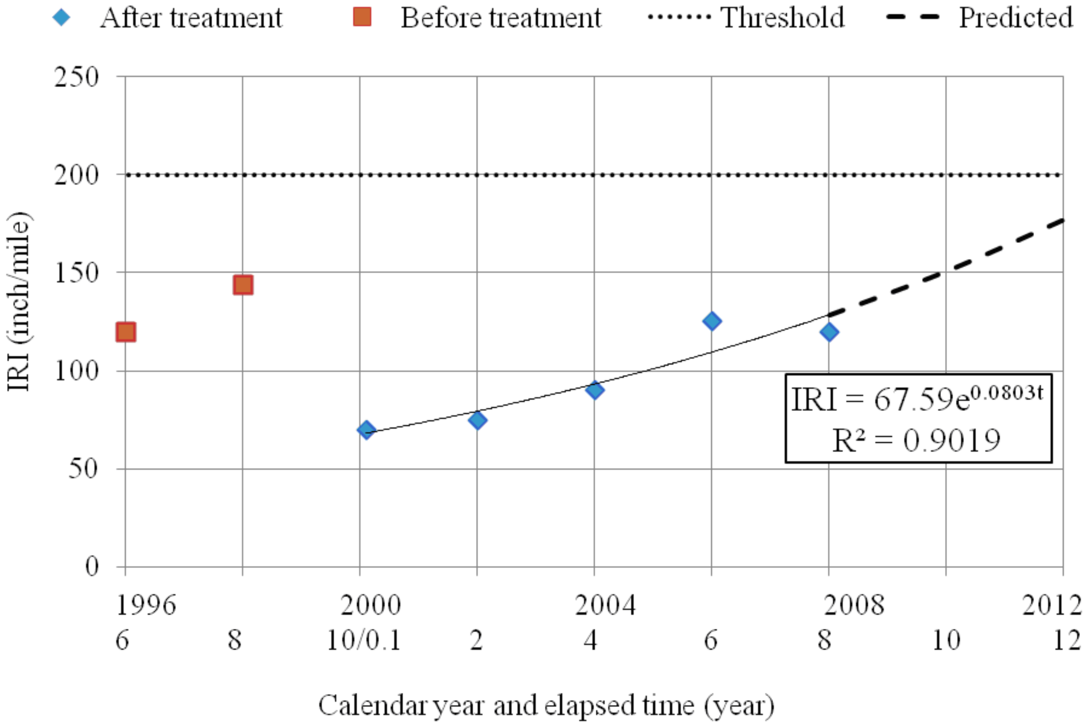


Figure 37

Calculation of RSL; insufficient before and adequate after treatment data

Step 3.3 - Data Analysis "Network Level RSL" – The calculated RSL values of step 3.1 could be subjected to further analyses at the network level in support of cost-effective decisions as enumerated below.

1. Assign to each pavement segment one of the five condition states (see step 3.2) based on its RSL value.
2. Group the various pavement segments according to their condition states. If the condition states (CSs) recommended in step 3.1 above are used, this should yield five CS groups.
3. Determine the distribution of the pavement network in the various condition states. This could be accomplished by dividing the number of 1/10th mile pavement segments in each CS group by the total number of the 1/10th mile pavement segments included in the analysis. The results could be used for many purposes such as:
    - Understanding the distribution of the CSs along the pavement network.
    - Calculating the longevity of the pavement network.
    - As the initial inputs to pavement treatment strategy analysis.
    - Estimating the minimum budget level that is needed to maintain the status quo of the pavement network.
    - Analyzing the impact of various budget levels on the longevity of the pavement network.
4. Calculate the weighted average RSL (the longevity) of the pavement network using equation (1) and the pavement network asset value in terms of lane-mile-years. This could be obtained by multiplying the average RSL value by the number of lane-mile under the agency jurisdiction.
5. Analyze the impact of the pavement expenditure level on the longevity of the pavement network through strategy analysis.
6. Determine the needed annual pavement expenditure level to maintain the status quo or to improve the pavement conditions. This is illustrated in the example below.

Example

- The size of the pavement network under the DOTD jurisdiction is 37,259 lane-miles and the current annual pavement expenditures is about $314 millions. These yield a current annual expenditure rate of $314 million divided by 37,259 lane miles or $8,427 per lane-mile.
- If the average life of the pavement sections that were subjected in one year to various treatment actions (thin and thick overlays, reconstruction, mill and fill, chipseal, and so forth) is 10 years, then the DOTD needs to treat annually 10% of the entire pavement network or 3,726 lane-miles in order to maintain the status quo regarding the pavement

condition. If the available annual pavement expenditures allow the DOTD to treat less than 3,726 lane-miles, the pavement condition will deteriorate over time. On the other hand, if more than 3,726 lane-miles are treated annually, the pavement condition will improve over time.

- For the above scenario, and based upon the annual pavement expenditures of $314 million, the cost per lane mile is $314 million divided by 3,726, which yields $84,273 per lane-mile. The DOTD cost data indicate that the average overlay cost for arterial is about $240,000 per lane mile (see Table 30 and Figure 32 and Figure 33). Hence, the DOTD cannot treat 10% of the pavement network on an annual basis.
- The needed annual pavement expenditures to maintain the status quo is that which would allow the DOTD to add, on average, 37,259 lane-mile-years of pavement performance or to the longevity of the pavement network every year. The reason is that, if no pavement treatment actions were taken, every one lane-mile of the 37,259 lane-miles network will lose 1 year of life for a total loss of 37,259 lane-mile years. Assume that the average cost per lane-mile of all road classes and all pavement and treatment types is $105,000 and the average treatment life is 10 years, then the average cost per lane-mile-year is $105,000 divided by 10 years or $10,500 per lane-mile-year. Thus the required budget to maintain the status quo is $10,500 multiplied by the size of the pavement network of 37,259 lane-miles, which yield minimum annual pavement expenditures of $391,219,500. Therefore, if the assumptions are correct, the pavement conditions will deteriorate if the current annual pavement expenditures do not increase.
- If one assumes that the current weighted average RSL of the pavement network is 8 years, then the current pavement network asset value is 37,259 lane-miles multiplied by 8 years, which yields 298,072 lane-mile-years.
- Similarly, the impacts of various annual pavement expenditure levels on the longevity of the pavement network could also be estimated.

Area 4 – Pavement Treatment Benefits. For each 1/10th mile pavement segment, six-pavement condition and distress data (IRI, rut depth, and alligator, transverse, longitudinal and random cracking) were subjected to the two acceptance criteria and then modeled as a function of time. Each of the resulting models was then used to calculate the pavement treatment benefits. Extensive literature review was conducted regarding methodologies for estimating pavement treatment benefits. Unfortunately no universally accepted method was found. In summary, the three potential methods that were found are the remaining service life (RSL), service life extension (SLE), and total benefit (TB). In addition, a fourth method was developed and used in this study called herein treatment life (TL). The TL (also shown in Figure 38) is defined as the after treatment time in years required for the pavement conditions and/or distress to reach the same level as those immediately before treatment. The after treatment RSL, the SLE, and the TL methods are illustrated in Figure 38.

Peshkins et al. approach as reported in the literature review section (Appendix B) of this report was also used in this study *[15]*. Several trials were made to calculate the total benefits using pavement condition and distress data obtained from various state highway agencies. The percent success was less than 5%. The calculated BT was very sensitive to the assumed after treatment improvement and rate of deterioration. When the master performance curve was used, the calculated TB values were not reasonable. Given the shortcoming of this methodology, it was not used in this study to estimate the treatment benefits.

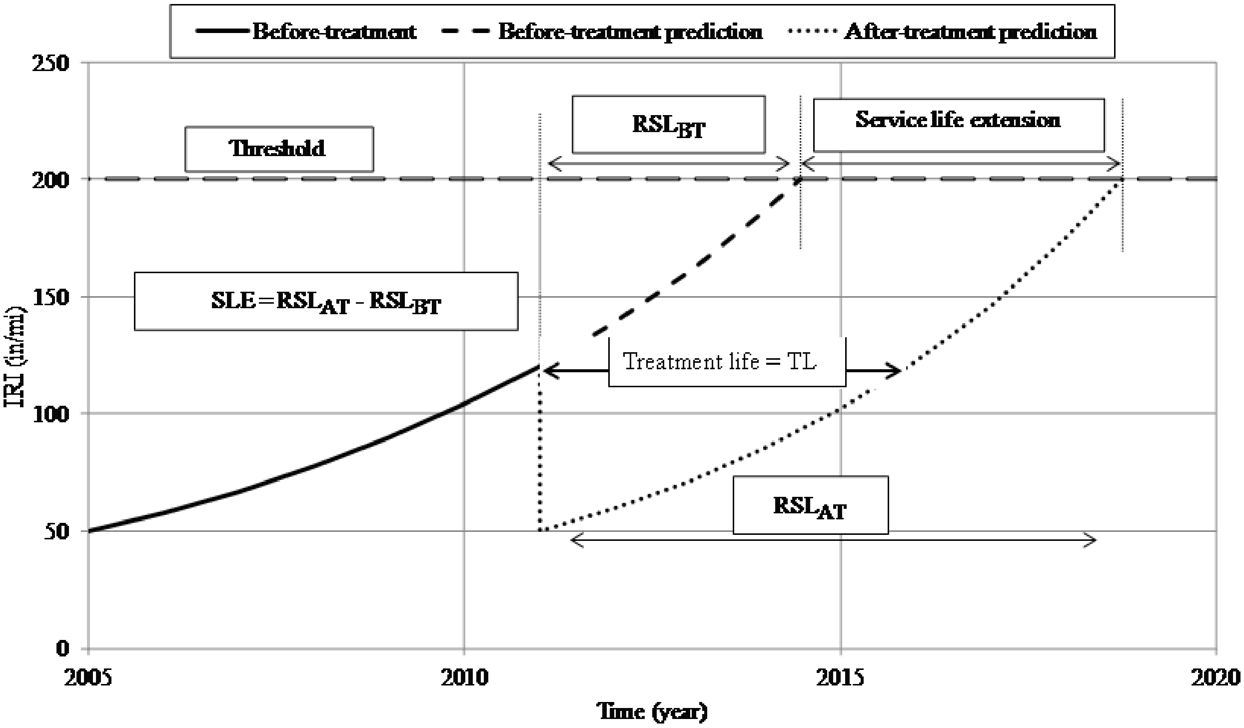


Figure 38
Schematic of the definition of AT RSL and SLE

Step 4.1 - After Treatment RSL - For each 1/10th mile pavement segment along a given pavement project and for each pavement distress and condition type, the AT RSL value (see Figure 38) could be calculated using:

a) The available AT time-series pavement condition and distress data.
b) The resulting best fit mathematical model from acceptance criterion 2.

c) The pre-specified threshold values listed established by the agency, examples thresholds are listed in Table 37.

It should be noted that the AT RSL does not directly account for the BT RSL or condition. Hence, the method does not address the net gain in the pavement service life due to the treatment; it simply estimates the AT longevity of the treated pavement segment in question. During the study it was observed that for some 1/10th mile pavement segments, the estimated RSL (longevity) was unreasonably large due mainly to two reasons:

1. The high variability of the time-series pavement condition and distress data, which produced high uncertainty in the performance model and hence in the estimated RSL values.

2. The available time-series pavement condition or distress data were measured during the early deterioration stage. They do not represent the later pavement rate of deterioration accurately. To illustrate, the pavement condition data of a pavement segment that were collected over seven-year period are shown by the open triangles in Figure 39. Using the seven data points (open triangles) and the best-fit exponential function, the RSL was estimated at 7 years. If only the first three data points (indicated by the solid triangles) of the same pavement segment were available and are used to obtain the best fit exponential function, then the estimated RSL value would be 32 years. Another illustrative example regarding data variability is shown in Figure 40 where the early three data points yield very short estimate of the RSL of 4 years relative to the estimated RSL of 12 years using the seven data points. Hence, the estimation of the RSL at early ages where the rate of deterioration is not well defined yet may cause over, under, or the correct estimation of the RSL value. While there is no solid engineering reasons that can be used to increase the under estimated AT RSL values, the overestimated values were reasonably limited to the assumed maximum treatment design service life of 25 years.

In this study, the AT RSL method or the longevity of the treated pavement segment was used along with two other methods to assess the effectiveness of the treatment.

Table 37
Pavement condition and distress threshold values used in this study

Pavement condition and distress types	BT and AT threshold values constituting zero RSL value
IRI	200 (in/mi)
Rut depth	0.5 (in)
Alligator (fatigue) cracking	10% of each wheel path or

	105.6 ft or 634 ft^2 per 1/10th mile
Longitudinal cracking	700 ft per 1/10th mile
Transverse cracking	700 ft per 1/10th mile
Random cracking	700 ft per 1/10th mile

Step 4.2 - Service Life Extension (SLE) - The SLE is the gain in the pavement service life due to the treatment. For each 1/10th mile pavement segment, the SLE could be calculated as the difference in years between the estimated BT and AT RSL values as shown in Figure 6. It should be noted that in case only three BT data points were available, the estimated BT RSL values are susceptible to the same shortcomings stated above and shown in Figure 39 and Figure 40. Therefore, the BT RSL values were limited to the assumed maximum BT design service life (DSL) of 25 years. In this study, the SLE of the treated pavement segment was also used to assess the effectiveness of the pavement treatment and to calibrate the trigger values.

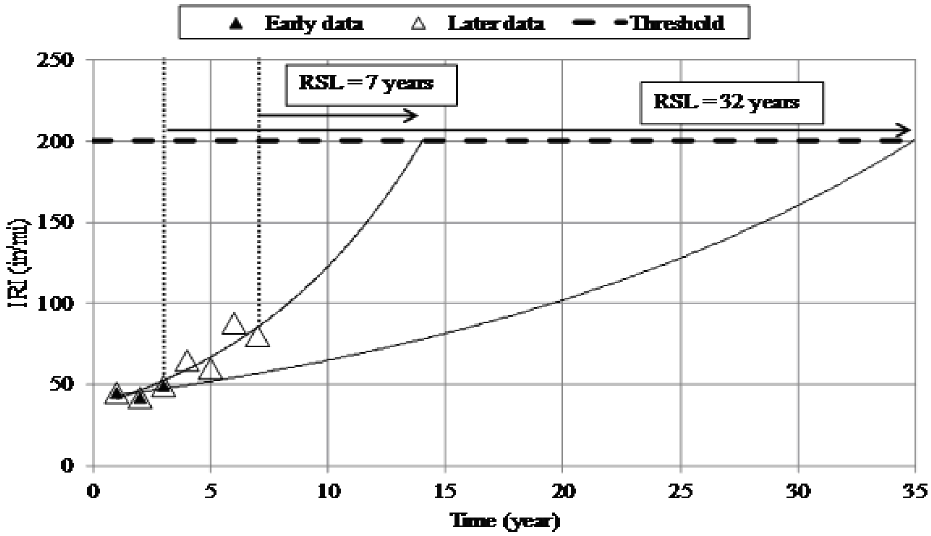


Figure 39

Overestimating RSL using three early measured IRI data points

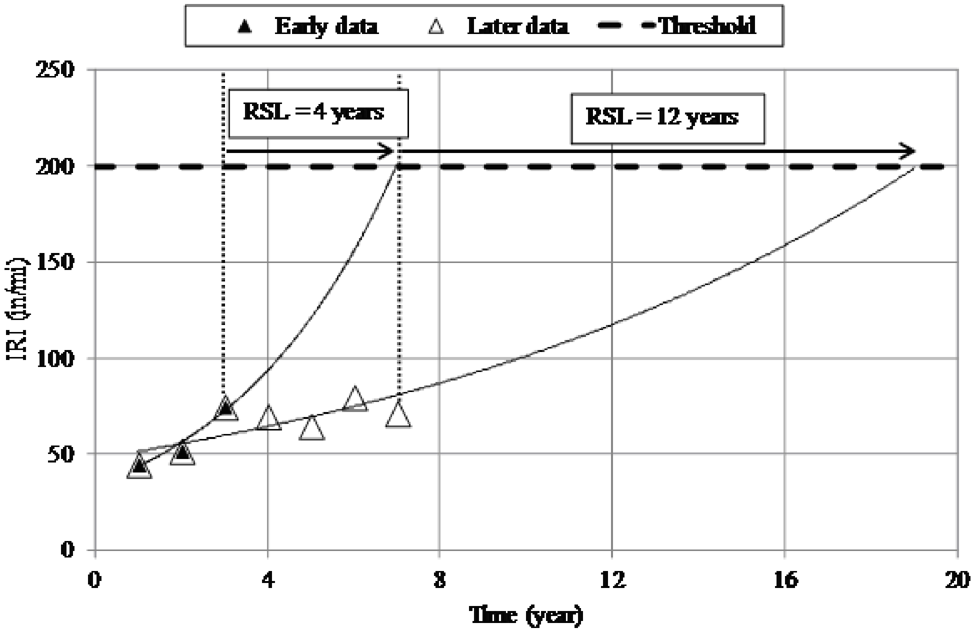


Figure 40
Underestimating RSL using three early measured IRI data points

Step 4.3 - Treatment Life (TL) - The TL is a new method that was developed by Dr. Baladi during the course of an FHWA sponsored study to calculate the treatment benefits. The TL is defined herein as the estimated time in years between the treatment year and the year when the AT pavement conditions or distresses reach the lesser of the threshold value or the BT pavement condition or distress as shown in Figure 41. Stated differently, for those pavement segments where the pavement condition or distress are better than the threshold value, the TL is the time in years for the AT condition to reach the same BT conditions when the treatment was applied. On the other hand, for those pavement segments where the BT pavement condition or distress are worse than the threshold value, the TL is the time in years for the AT pavement conditions to reach the threshold value. For each pavement condition and distress type, the estimation of TL requires the following information:

1. The last BT measured pavement condition or distress data.
2. A minimum of three measured AT pavement condition or distress data over time.
3. The threshold value of the condition or distress in question.

For each pavement treatment type and for those 1/10th mile pavement segment where the AT time dependent distress and condition showed insignificant deterioration (the data yielded very large TL), the maximum TL value was assumed to be equal to the largest of the AT pavement surface age or the treatment life limits (TLLs) reported in the literature and listed in Table 38.

Table 38
TLL values reported in the literature and used in the TL analyses

Treatment type	References	Estimated treatment life limit (year)	
		Louisiana data/Survey	From References
Thin HMA overlay	Geoffroy *[16],* Hicks et al. *[17],* Johnson *[18],* ODOT *[19],* Wade et al. *[20],* Peshkin et al. *[15]*	10	8
Thick HMA overlay	FHWA *[21]*	11	10
Single chipseal	Geoffroy *[16],* Hicks et al. *[17],* Johnson *[18],* Bolander [*22],* Gransberg & James *[23]*	5	6
Double chipseal	Hicks et al. *[17],* Johnson *[18],*	7	9
Thin mill & fill	FHWA *[21]*	10	8
Thick mill & fill	FHWA *[21]*	11	10
Single course microsurfacing		6	-
Multi courses microsurfacing		8	-

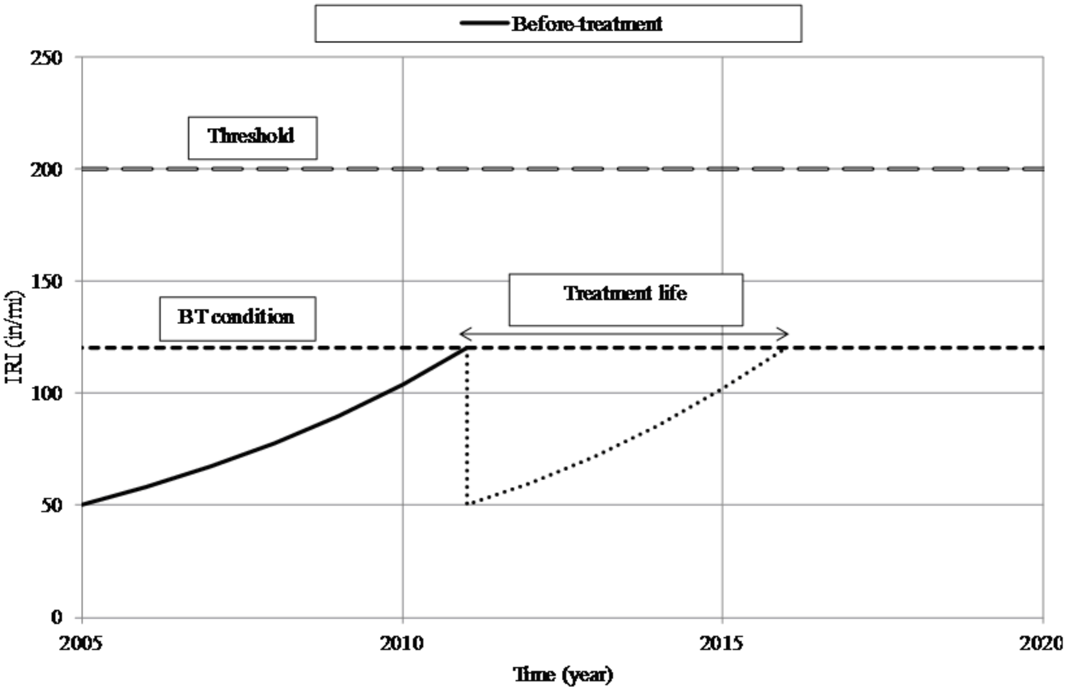


Figure 41
Schematic of the definition of treatment life (TL)

Figure 42 illustrates the TL concept using the measured IRI data along 4.8 mile long pavement project along US-165, in Louisiana. Each of the solid diamonds in the Figure 42 represents the measured IRI data BT, whereas each of the open squares represents the first AT measured IRI data. Note that in few locations (beginning mile points (BMPs) 1.6, 2, and 2.2) the BT or the AT data are missing. It is common for few data points to be missing along some pavement projects. The data could be missing for several reasons, such as obstruction of the data collection lane, malfunction in the equipment during the data collection process, or data storage problem. Nevertheless, for each 1/10th mile pavement segment, the TL is the required time for the AT condition or distress to mirror the BT condition or distress or to reach the threshold value whatever is shorter. As indicated in the Figure 42, for few 1/10th mile pavement segments such as the beginning mile points (BMPs) 0.3, 0.6, and 0.9, the treatment was applied when the BT IRI was higher than the threshold value. In this case the TL is the time for the AT IRI to reach the threshold value. On the other hand, in certain other scenarios such as at BMP 4.8, and for multiple reasons, the measured IRI value immediately after the application of the treatment is worse than the BT IRI value (the treatment caused negative performance jump (PJ)). This could have been a result of poor construction practices where the HMA overlay did not smooth the pavement surface. The HMA overlay may have mirrored and magnified existing rough areas along the project, increased the roughness in other areas by applying too thick or thin HMA overlay, or by compacting the HMA in discontinuous movements of the roller or at improper temperatures. In these scenarios, the TL is calculated as the negative number of years for the BT pavement condition to reach the AT pavement condition assuming the do-nothing alternative. Hence, negative treatment life values represent the “loss” in years of the BT pavement life due to the applied treatment. The negative TL value is further illustrated in Figure 43, where the AT IRI, shown by the dotted line, is about 50 inch/mile higher than the BT IRI value, and the estimated TL is (-)3 years. Finally, the absolute value of the negative TL has the same limitations as the BT RSL. The TL method is used in this study as a measure of the treatment benefits or effectiveness.

A summary of the advantages and shortcomings of the three treatment benefits used in this study are listed in Table 39. The AT RSL, SLE, and TL methods are practical and can be easily understood. The benefit (in years) could be easily expressed to engineers, managers, legislators, and the public. The main shortcoming of the AT RSL is that it does not reference the do-nothing alternative. In some scenarios, the AT RSL could be shorter than the BT RSL implying negative net gain in the pavement service life. To express the gain or loss in the pavement service life, the SLE is calculated. The main shortcoming of the SLE is that the times required for the pavement conditions to reach the threshold value BT and AT have to be predicted. The errors in each or both predictions could be significant depending on the variability of the data and the number of available data points. Hence, the RSL values could be over or underestimated. To reduce the amount of prediction, the TL method was developed where no BT prediction has to be made and shorter AT time prediction is required. Nevertheless, for each 1/10th mile pavement segment, the AT RSL, SLE, and TL were calculated and discussed in this study. Finally, a computer program using advanced Matrix Analysis Laboratory (MATLAB) software was developed to calculate the pavement treatment benefits. The outputs of the program (the treatment benefits) for each 1/10th mile pavement segment were used in Microsoft Excel file and used to populate the treatment transition matrices (T2M), which are presented and discussed in the next few subsections.

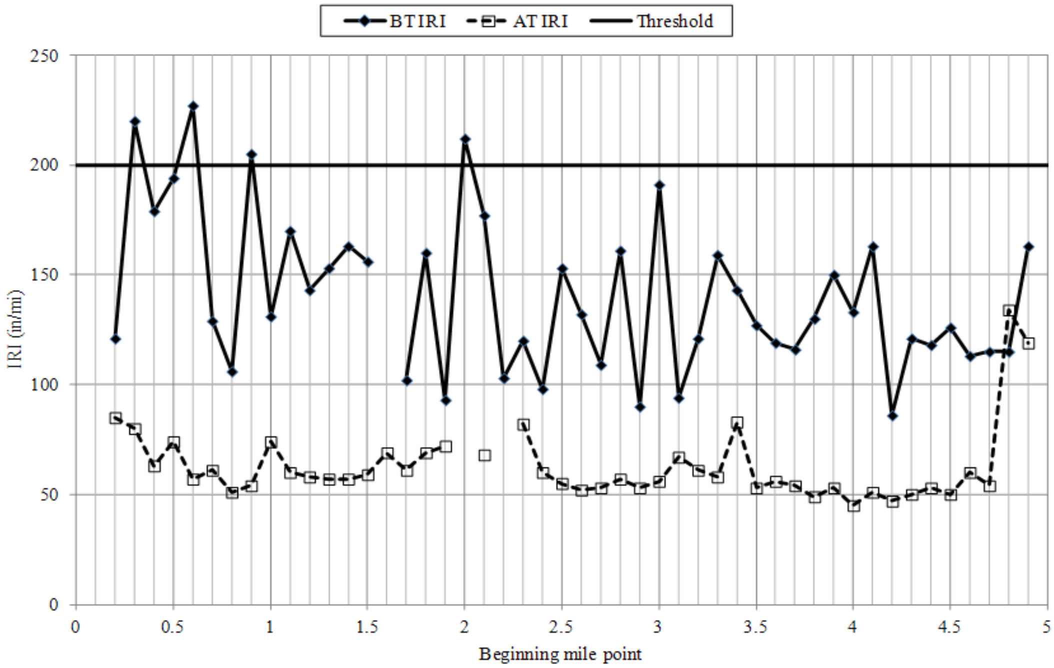


Figure 42

Before and after treatment pavement condition along 4.8 mile long pavement project along US-165, Louisiana

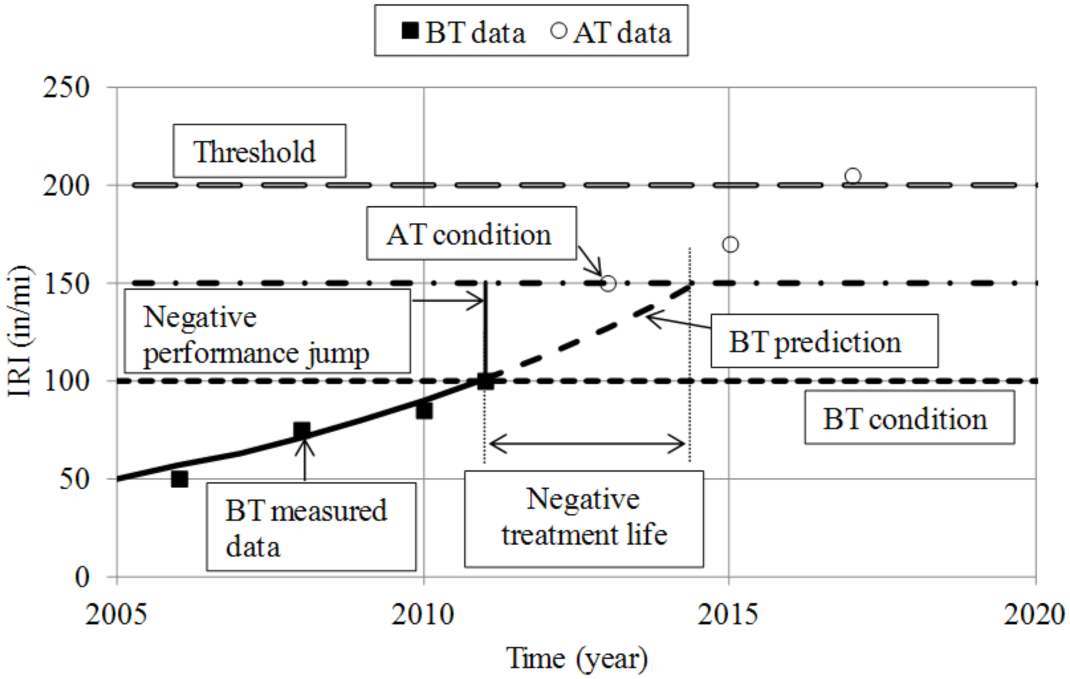


Figure 43
Schematic of negative performance jump and the definition of negative TL

Table 39
Advantages and shortcomings of five pavement treatment benefit methods

Treatment benefit method	Advantages	Shortcomings
AT RSL	Expresses the remaining years of service Expresses all pavement condition and distress types with the same benefit unit (year) Judges all pavement segments or sections on the same threshold Expresses pavement longevity	Reference to the do-nothing scenario is not included Requires condition predictions to AT threshold value
SLE	Expresses the number of years of service gained or lost Expresses all pavement condition and distress types with the same benefit unit (year) Judges all pavement segments or sections on the same threshold	Requires predictions of the AT and BT pavement conditions to the threshold value
TL	Expresses the number of years until BT conditions return Requires minimal prediction of condition AT and none for BT Expresses all pavement condition and distress types with the same benefit unit (year) Expresses the number of years gained or lost due to the treatment	At a glance negative treatment life might be confusing for some

Step 4.4 - Data Analysis - Project Level – The calculated RSL could be subjected to further analyses at the project level. These include:

1. Use the calculated RSL values before and after treatment of each pavement project based on each distress type and determine the percent of the project in each condition state before and after treatment. List the results in a project treatment transition matrix (PT^{2}M) as shown in Table 40 to Table 42. Each of the three tables is divided into three regions. The left-hand side region for before treatment (BT) data, the middle region for the after treatment (AT) data, and the right-hand region for treatment benefits (TB). The before treatment data in the three tables are expressed by the number and the percent of the 1/10th mile pavement segments along the project in certain condition state before treatment. Whereas, the after treatment data in the three tables are expressed as follows:
   - Table 40 lists the numbers of the 1/10th mile pavement segments transitioned from each before treatment condition state to each after treatment condition state. That is the sum of all 1/10th mile pavement segment in any one row in the after treatment section of the table is equal to the number of the 1/10th mile pavement segments in each before treatment condition state.
   - Table 41 lists the percent of the pavement projects transitioned to each after treatment condition state. That is the sum of all percentages in the after treatment section of the table is equal to 100% of all projects.
   - Table 42 lists the percent of the 1/10th mile pavement segments in each before treatment condition state transitioned to each after treatment condition state due to the treatment. That is the sum of the percentages of each row in the after treatment section of the table is equal to 100%.

Nevertheless, for the three tables, the data along the diagonal in each of the after treatment section represent no gain in RSL due to the treatment. The data above the diagonal represent gains in RSL due to the treatment. Finally, the data below the diagonal represent losses in RSL due to the treatment.

Calculate due to the treatment in terms of treatment life (TL), service life extension (SLE) and RSL after treatment. The three terms are illustrated in Figure 38. For each condition state, the benefits could be calculated based on the average of the RSL range of that condition state. List the results in the right-hand regions of the PT^{2}M, as shown in Table 40 through Table 42.

Step 4.5 - Data Analysis – Treatment Type Level – For all pavement projects that were subjected to one pavement treatment type (e.g., thin overlay, thick overlay, mill and fill, chipseal, etc.), use the calculated RSL to analyze the effectiveness of the treatment type as enumerated below.

1. Search the database to identify all pavement projects that have the same road class, the same pavement type, and have received certain treatment type in the past. Calculate the RSL values according to step 3.1 above.
2. Calculate the total length of all identified pavement projects and multiply the results by 10 to obtain the overall total number of 1/10th mile pavement segments that were subjected to the same treatment type.
3. For each distress type, add all 1/10th mile pavement segments of all projects that have received the same treatment type and have the same road class, pavement type, and the same before treatment condition state or RSL bracket. List the results in the left-hand region of the treatment transition matrix (T^2M), as shown in the examples listed in Table 43 through Table 49. It should be noted that the analysis results listed in Table 43 through Table 49 are based on the same road class, pavement type, and distress type. Further, the results listed in the tables are based on rut depth and IRI and on rut depth deduct point threshold and the IRI deduct point threshold as indicated below.
   - Table 43 and Table 44 list all pavement projects along arterial roads that received in the past 3.5-in. HMA overlay. The analysis is based on rut depth data and rut depth threshold value of 0.5-in. (Table 43) and the existing DOTD deduct point threshold value of 35 points (Table 44).
   - Table 45 and Table 46 list all pavement projects along arterial roads that received in the past 3.5-in. HMA overlay. The analysis is based on available IRI data and IRI threshold value of 200 inch/mile (Table 45) and the existing DOTD deduct point threshold value of 35 points (Table 46).
   - Table 47 and Table 48 list all pavement projects along collector roads that received in the past 2-in. HMA overlay. The analysis is based on the rut depth data and rut depth threshold value of 0.5-in. (Table 47) and the existing DOTD deduct point threshold value of 35 points (Table 48).
   - Table 49 and Table 50 list all pavement projects along collector roads that received in the past 2-in. HMA overlay. The analysis is based on the IRI data and IRI threshold value of 200 inch/mile (Table 49) and the existing DOTD deduct point threshold value of 30 points (Table 50).

4. Repeat item 3 above for the after treatment data and list the results in the middle regions of Table 43 to Table 50 .
5. Calculate the average benefits of the treatment type based on all projects and list the results in the right-hand region of the T^2M as shown in Table 43 through Table 50

Note that the data listed in Table 43 through Table 50 are parallel to those of Table 40 through Table 43. The difference is that the former tables include, for one road class and pavement type, all pavement projects received the same treatment type. The data in Table 40 through Table 43, on the other hand, address one project at a time.
In addition, the results listed in Table 43 through Table 50 could be presented as a bar chart expressing the distribution of the number of 1/10th mile pavement segments in the various condition states. Examples of such charts are depicted in Figure 44 and Figure 45.

Finally, the results listed in Table 43 through Table 50 could be tailored to address the state-of-the-practice in the various districts. In this case, the results could be used to compare the state-of-the-practices between the various districts.

Table 40

Project treatment transition matrix (T2M) for 7.4 mile long project (7.2 mile was accepted for analysis) subjected to 2-in. HMA overlay in 2001, LA-9, control section 043-06-1, direction 1, District 4, Louisiana, the after treatment section lists the number of 1/10th mile pavement segments

Condition/distress type: condition/distress causing the minimum RSL												
Before treatment (BT) data					After treatment (AT) data					Benefits		
					Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the number of the 1/10th mile pavement segments transitioned from each before treatment (BT) CS or BT RSL bracket to each of the indicated after treatment (AT) CS or AT RSL brackets					Treatment benefits in terms of treatment life (TL), service life extension (SLE), and RSL of the treatment (year)		
Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Standard error (SE)	1	2	3	4	5	Treatment life (TL)	Service life extension (SLE)	RSL
					0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
		Number	Percent		SE of each CS or RSL bracket							
					---	---	---	---	---			
1	0 to 2	64	89	---	**1**	24	33	4	2	6	6	7
2	3 to 5	3	4	---	0	**1**	**1**	**0**	**1**	7	7	11
3	6 to 10	3	4	---	0	0	**2**	**0**	**1**	6	4	12
4	11 to 15	1	1	---	0	1	0	**0**	**0**	2	-9	4
5	16 to 25	1	1	---	0	0	0	0	**1**	10	0	21
Total		72	100	---	1	26	36	4	5	6	6	8

Table 41

Project treatment transition matrix (T2M) for 7.4 mile long project (7.2 mile was accepted for analysis) subjected to 2-in. HMA overlay in 2001, LA-9, control section 043-06-1, direction 1, District 4, Louisiana, the after treatment section lists the percent of the total project (the percent of the 1/10th mile pavement segments)

Condition/distress type: condition/distress causing the minimum RSL												
Before treatment (BT) data					After treatment (AT) data							
					Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the percent of the project (1/10th mile pavement segments) transitioned from each before treatment (BT) CS or BT RSL bracket to each of the indicated after treatment (AT) CS or AT RSL brackets					Treatment benefits in terms of treatment life (TL), service life extension (SLE), and RSL of the treatment (year)		
Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Standard error (SE)	1	2	3	4	5	Treatment life (TL)	Service life extension (SLE)	RSL
					0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
		Number	Percent		SE of each CS or RSL bracket							
					---	---	---	---	---			
1	0 to 2	64	89	---	**1.4**	33.3	45.8	5.6	2.8	6	6	7
2	3 to 5	3	4	---	0.0	**1.4**	1.4	0.0	1.4	7	7	11
3	6 to 10	3	4	---	0.0	0.0	**2.8**	0.0	1.4	6	4	12
4	11 to 15	1	1	---	0.0	1.4	0.0	**0.0**	0.0	2	-9	4
5	16 to 25	1	1	---	0.0	0.0	0.0	0.0	**1.4**	10	0	21
Total		72	100	---	1	1.4	36.1	50.0	5.6	6.9	6	8

Table 42

Project treatment transition matrix (T2M) for 7.4 mile long project (7.2 mile was accepted for analysis) subjected to 2-in. HMA overlay in 2001, LA-9, control section 043-06-1, direction 1, District 4, Louisiana, the after treatment section lists the percent of the 1/10th mile pavement segments in each before treatment condition state

Condition/distress type: condition/distress causing the minimum RSL												
Before treatment (BT) data					After treatment (AT) data							
					Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the percent of the 1/10th mile pavement segments in each before treatment (BT) CS or BT RSL bracket transitioned to each of the indicated after treatment (AT) CS or AT RSL brackets					Treatment benefits in terms of treatment life (TL), service life extension (SLE), and RSL of the treatment (year)		
Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Standard error (SE)	1	2	3	4	5	Treatment life (TL)	Service life extension (SLE)	RSL
					0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
		Number	Percent		SE of each CS or RSL bracket							
					---	---	---	---	---			
1	0 to 2	64	89	---	**1.6**	37.5	51.6	6.3	3.1	6	6	7
2	3 to 5	3	4	---	0.0	**33.3**	33.3	0.0	33.3	7	7	11
3	6 to 10	3	4	---	0.0	0.0	**66.7**	0.0	33.3	6	4	12
4	11 to 15	1	1	---	0.0	100.0	0.0	**0.0**	0.0	2	-9	4
5	16 to 25	1	1	---	0.0	0.0	0.0	0.0	**100.0**	10	0	21
Total		72	100	---	1	1.4	36.1	50.0	5.6	6.9	6	8

Table 43
Treatment transition matrix for the 1/10th mile pavement segments of pavement projects located along arterial roads that were subjected to 3.5-in. HMA overlay, the data are based on rut depth threshold value of 0.5-in.

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the number of the 1/10th mile pavement segments in each before treatment (BT) CS or BT RSL bracket transitioned to each of the indicated after treatment (AT) CS or AT RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life (TL)	Service life extension (SLE)	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
							0.08	0.12	0.03	0.02			
A	1	0 to 2	109	31	0.12	**0**	0	1	2	106	10	19	20
B	2	3 to 5	20	6	0.11	0	**0**	0	0	20	10	16	20
C	3	6 to 10	20	6	0.12	0	0	**1**	0	19	10	11	19
D	4	11 to 15	62	18	0.09	0	0	1	**3**	58	9	6	19
E	5	16 to 25	143	40	0.09	0	1	0	0	**142**	10	0	20
F	Total		354	100		0	1	3	5	345	10	8	20

Table 44

Treatment transition matrix for the 1/10th mile pavement segments of pavement projects located along arterial roads that were subjected to 3.5-in. HMA overlay, the data are based on rut depth deduct point threshold value of 35 points

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the number of the 1/10th mile pavement segments in each before treatment (BT) CS or BT RSL bracket transitioned to each of the indicated after treatment (AT) CS or AT RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
							7.32	6.60	2.16	2.27			
A	1	0 to 2	80	30	11.61	**0**	0	2	2	76	10	19	20
B	2	3 to 5	21	8	10.49	0	**0**	0	0	21	10	16	20
C	3	6 to 10	23	9	10.25	0	0	**0**	0	23	10	12	20
D	4	11 to 15	51	19	6.44	0	0	4	**4**	43	9	6	19
E	5	16 to 25	94	35	7.88	0	1	0	0	**93**	10	0	20
F	Total		269	100		0	1	6	6	256	10	9	20

Table 45

Treatment transition matrix for the 1/10th mile pavement segments of pavement projects located along arterial roads that were subjected to 3.5-in. HMA overlay, the data are based on IRI threshold value of 200 inch/mile

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the number of the 1/10th mile pavement segments in each before treatment (BT) CS or BT RSL bracket transitioned to each of the indicated after treatment (AT) CS or AT RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
							57	12	6	4			
A	1	0 to 2	189	64	30	**0**	3	9	17	160	10	18	19
B	2	3 to 5	34	12	18	0	**0**	5	5	24	10	13	17
C	3	6 to 10	18	6	16	0	0	**1**	4	13	10	10	18
D	4	11 to 15	17	6	12	0	0	0	**1**	16	10	7	20
E	5	16 to 25	37	13	18	0	0	4	3	**30**	9	-2	18
F	Total		295	100		0	3	19	30	243	10	14	18

Table 46

Treatment transition matrix for the 1/10th mile pavement segments of pavement projects located along arterial roads that were subjected to 3.5-in. HMA overlay, the data are based on IRI deduct point threshold value of 30 points

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the number of the 1/10th mile pavement segments in each before treatment (BT) CS or BT RSL bracket transitioned to each of the indicated after treatment (AT) CS or AT RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
							14	2	1	1			
A	1	0 to 2	206	68	6	**0**	8	67	33	98	9	13	14
B	2	3 to 5	25	8	4	0	**0**	14	3	8	8	8	12
C	3	6 to 10	17	6	4	0	0	**11**	2	4	8	3	11
D	4	11 to 15	24	8	4	0	1	8	**2**	13	8	2	15
E	5	16 to 25	33	11	4	0	1	17	5	**10**	8	-8	12
F	Total		305	100		0	10	117	45	133	9	9	14

Table 47

Treatment transition matrix for the 1/10th mile pavement segments of pavement projects located along collector roads that were subjected to 3.5-in. HMA overlay, the data are based on rut depth threshold value of 0.5-in.

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the percent of the 1/10th mile pavement segments in each before treatment (BT) CS or BT RSL bracket transitioned to each of the indicated after treatment (AT) CS or AT RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in)							
						0.42		0.14		0.03			
A	1	0 to 2	370	26	0.09	**2**	0	2	0	366	10	19	20
B	2	3 to 5	54	4	0.07	0	**0**	0	0	54	10	16	20
C	3	6 to 10	74	5	0.06	0	0	**0**	0	74	10	12	20
D	4	11 to 15	217	15	0.06	0	0	0	**0**	217	10	7	20
E	5	16 to 25	709	50	0.06	0	0	0	0	**709**	10	0	20
F	Total		1424	100		2	0	2	0	1420	10	7	20

Table 48

Treatment transition matrix for the 1/10th mile pavement segments of pavement projects located along collector roads that were subjected to 3.5-in. HMA overlay, the data are based on rut depth deduct point threshold value of 35

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the number of the 1/10th mile pavement segments in each before treatment (BT) CS or BT RSL bracket transitioned to each of the indicated after treatment (AT) CS or AT RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
						64.90	48.17	12.99		2.19			
A	1	0 to 2	80	26	7.89	**1**	1	1	0	77	10	18	19
B	2	3 to 5	22	7	6.19	0	**0**	1	0	21	10	15	19
C	3	6 to 10	30	10	6.95	0	0	**0**	0	30	10	12	20
D	4	11 to 15	37	12	5.09	0	0	0	**0**	37	10	7	20
E	5	16 to 25	144	46	4.93	0	0	0	0	**144**	10	0	20
F	Total		313	100		1	1	2	0	309	10	8	20

Table 49

Treatment transition matrix for the 1/10th mile pavement segments of pavement projects located along collector roads that were subjected to 3.5-in. HMA overlay, the data are based on IRI threshold value of 200 inch/mile

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the number of the 1/10th mile pavement segments in each before treatment (BT) CS or BT RSL bracket transitioned to each of the indicated after treatment (AT) CS or AT RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
						1	71	20	11	4			
A	1	0 to 2	728	56	28	2	8	48	73	597	10	17	18
B	2	3 to 5	104	8	16	0	0	5	3	96	10	15	19
C	3	6 to 10	122	9	13	0	0	5	6	111	10	11	19
D	4	11 to 15	128	10	11	0	1	2	4	121	10	6	19
E	5	16 to 25	216	17	8	0	0	4	3	209	10	0	20
F	Total		1298	100		2	9	64	89	1134	10	13	19

Table 50

Treatment transition matrix for the 1/10th mile pavement segments of pavement projects located along collector roads that were subjected to 3.5-in. HMA overlay, the data are based on IRI deduct point threshold value of 40 points

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						Condition state (CS) or RSL bracket number and range in years, the standard error (SE) for each CS or RSL bracket, and the percent of the 1/10th mile pavement segments in each before treatment (BT) CS or BT RSL bracket transitioned to each of the indicated after treatment (AT) CS or AT RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	Condition state or RSL bracket number	RSL bracket range (year)	1/10th mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in/mi)							
			Number	Percent			13	2	1	1			
A	1	0 to 2	459	37	7	**0**	10	111	77	261	9	15	16
B	2	3 to 5	124	10	5	0	**1**	29	30	64	9	11	15
C	3	6 to 10	155	13	3	0	4	**33**	33	85	9	8	16
D	4	11 to 15	171	14	3	0	2	36	**29**	104	9	3	16
E	5	16 to 25	325	26	2	0	0	46	80	**199**	9	-3	17
F	Total		1234	100		0	17	255	249	713	9	7	16

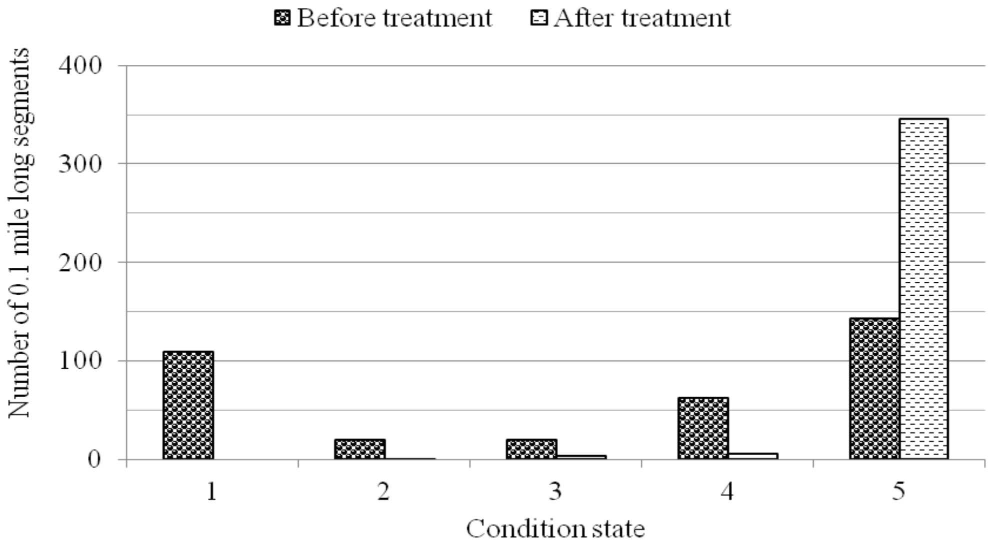


Figure 44

The before and after treatment distributions of the condition state of 35.4 lane-miles pavement projects along arterial roads that were subjected to 3.5-in. HMA overlay, based on RSL due to rut depth data, and rut depth threshold value of 0.5 in.

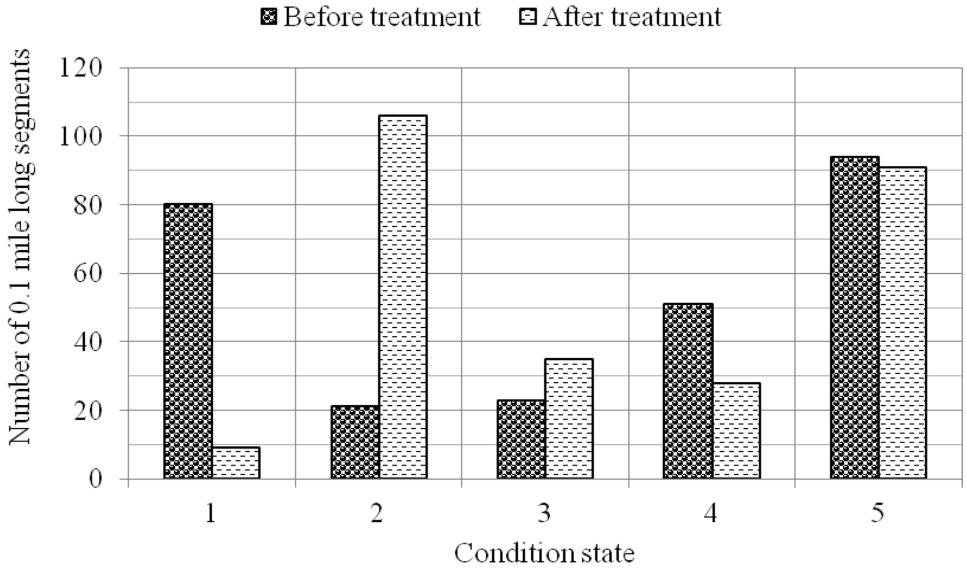


Figure 45

The before and after treatment distributions of the condition state of 26.9 lane-miles pavement projects along arterial roads that were subjected to 3.5-in. HMA overlay, based on RSL due to rut depth data, and rut depth deduct point threshold of 35 points

Step 4.6 - Data Analyses - State-of-the-practice - For each pavement condition or distress, road class, treatment, and pavement type – populate the treatment transition matrices (T^2M). The data in the T^2M represent the before treatment distribution of the pavement segments in the various condition states and the after treatment distribution in the various condition states. For example, the data shown in Table 50 indicate that 123.4 lane-miles (1234 of 0.1-mile long pavement segments) along collector roads were subjected to 3.5-in. hot mix asphalt overlay in Louisiana during several consecutive construction seasons and the listed data passed the two data acceptance criteria.

The distributions of the condition state of the 123.4 lane-mile relative to IRI before and after treatment are listed in the table. Such distributions reflect the state-of-the-practice in Louisiana regarding project and treatment selection and indicate that:

1. The distribution of the pavement condition relative to the IRI data along the projects varies as follows:

    - On average 45.9 miles (459 1/10th mile pavement segments) or 37% of the selected projects is in condition state 1 (worst state/poor condition) before treatment.
    - 12.4 lane miles (124 1/10th mile pavement segments) or 10% of the selected projects is in condition state 2 (fair condition) before treatment.
    - 15.5 lane miles (155 1/10th mile pavement segments) or 13% of the selected projects is in condition state 3 (good condition) before treatment.
    - 17.14 lane miles (171 1/10th mile pavement segments) or 14% of the selected projects is in condition state 4 (very good condition) before treatment.
    - 32.5 lane miles (325 1/10th mile pavement segments) or 26% of the selected projects is in condition state 5 (best state/excellent condition) before treatment.

2. The distribution of the 45.9 miles in the after treatment condition states is as follows:

    - Zero lane-mile remained in condition state 1.
    - The condition of one lane-mile or 10 1/10th mile pavement segments improved from CS 1 to CS2 (poor to fair).
    - The condition of 11.1 lane-miles or 111 1/10th mile pavement segments improved from CS 1 to CS3 (poor to good).
    - The condition of 7.7 lane-miles or 77 1/10th mile pavement segments improved from CS 1 to CS4 (poor to very good).
    - The condition of 26.1 lane-miles or 261 1/10th mile pavement segments improved from CS 1 to CS5 (poor to excellent).

3. The remaining after treatment distribution is detailed in Table 50 .
4. The number of 1/10th mile pavement segments in condition state 1 (poor condition) before treatment decreased from 459 to 0.0 after treatment.
5. The number of 1/10th mile pavement segments in condition state 2 (fair condition) before treatment decreased from 124 to 17 after treatment.
6. The number of 1/10th mile pavement segments in condition state 3 (good condition) before treatment increased from 155 to 255 after treatment.
7. The number of 1/10th mile pavement segments in condition state 4 (very good condition) before treatment increased from 171 to 249 after treatment.
8. The number of 1/10th mile pavement segments in condition state 1 (excellent condition) before treatment increased from 325 to 713 after treatment.

It should be noted that the above observations should be made for each pavement condition and distress type. In reality, after generating one treatment transition matrix per for each pavement condition and distress type, the pavement condition or distress that yields the minimum benefits in terms of after treatment LE, SLE, and, RSL, can be considered as the controlling condition or distress. Knowing the cost of the treatment, the cost to benefit ratio could be calculated to populate the cost to benefits matrix for all treatment types. To illustrate, Table 33 and Table 34 provide the before and after treatment distributions of the condition states of all thin HMA overlay projects that were conducted in three consecutive construction seasons. In both tables, the after treatment data are based on the lowest RSL value among all pavement condition and distress types. It can be seen from the before treatment section of the Table 33 that 43.9 miles or 439 1/10th mile pavement segments were subjected to thin HMA overlay and passed the two acceptance criteria of step 2.10. Please note that the 439 1/10th mile pavement segments accepted in the analysis based on the lowest after treatment RSL value is higher than the 219 1/10th mile pavement segments accepted in the analysis based on the IRI data and listed in Table 33.

Once again, for a given treatment type and pavement projects, the number of 1/10th mile pavement segments that pass the two acceptance criteria of step 2.10 varies and is a function of the type of pavement condition and distress type being considered. For example, the number of 1/10th mile pavement segments that were subjected to thin HMA overlay and passed the two acceptance criteria of step 2.10 based on each pavement condition and distress type in the state of Louisiana is listed in Table 33.

Step 4.7-Data Analysis – “Uses of T^2M” - The data presented in the T^2M could be further scrutinized and analyzed to determine:

1. **The Optimum Treatment Strategy –** Analysis of the optimum treatment strategy requires the following two input categories that could be easily obtained from the T^2M (see page 42):

   - The initial probability distribution of the pavement network in the various condition states. Relative to Table 42, these are the percentages of the pavement projects in each of the five before treatment condition states.

   - The probabilities that the pavement segments will be transitioned to the various condition states due to the treatment. These probabilities are listed in the after treatment section of Table 42.

2. **The Selection of Optimum Project Boundaries -** To illustrate, the before treatment section of Table 50 indicate that 26% of the 123.4 lane-miles along collector roads that were subjected to 3.5-in. HMA overlay is in excellent condition and 14% is in very good condition. These sections could be identified prior to treatment and, if possible, excluded from the overlay. Hence, the boundaries of HMA overlay projects could be determined.

3. **Treatment Types Selection -** This could be accomplished by generating one T^2M per pavement condition and distress type and then comparing the costs and benefits of each treatment. To do so however, the database must contain sufficient time series pavement distress data, detailed cost data, and detailed action plan along each project.

4. **The Optimum Time or the deduct point trigger values –** This is detailed in the results section of this report.

5. **Feedback -** The needed feedback system to improve the state-of-the-practice. For example, for each treatment, pavement, and distress type, one T^2M can be produced per district or region within a given highway agency. However, at this point in time, if the pavement treatment is treated discretely, the database will not have significant number of projects to arrive at a relatively solid decision. Having said that, various treatments could be combined to increase the number of projects. For example, all HMA overlays of flexible pavements could be divided into two categories; 2.5-in. or less HMA overlays (thin overlays) and more than 2.5-in. HMA overlay (thick overlay). After such combination of the data, Figure 46 and Figure 47 were produced.

   Figure 46 shows, for each district in the state of Louisiana, the benefits of thick HMA overlay and the state average benefits. The same information for thin HMA overlay is shown in Figure 47.

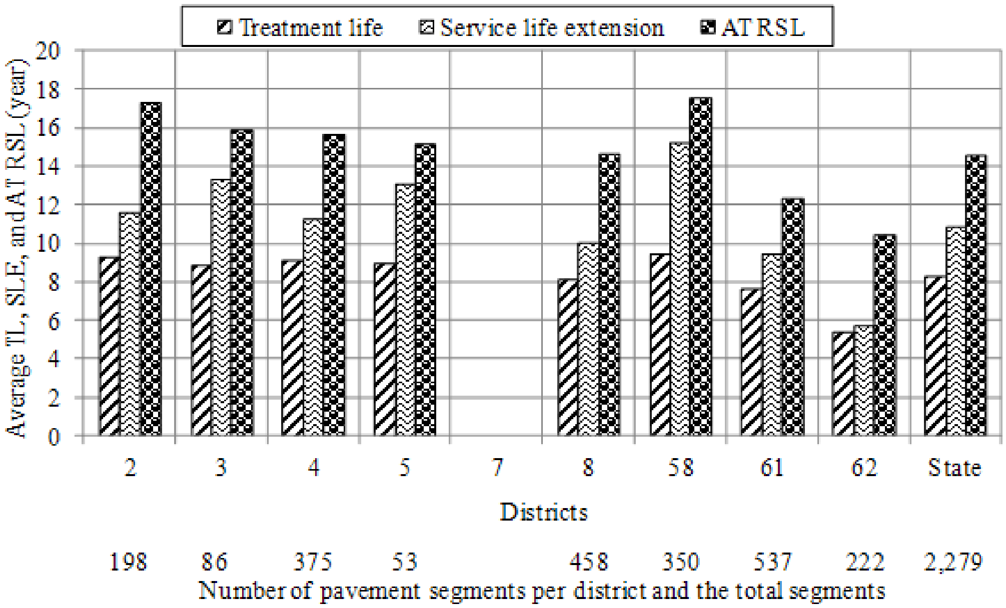


Figure 46

Treatment benefits for thick HMA overlay of asphalt surfaced pavement projects, all districts, state of Louisiana

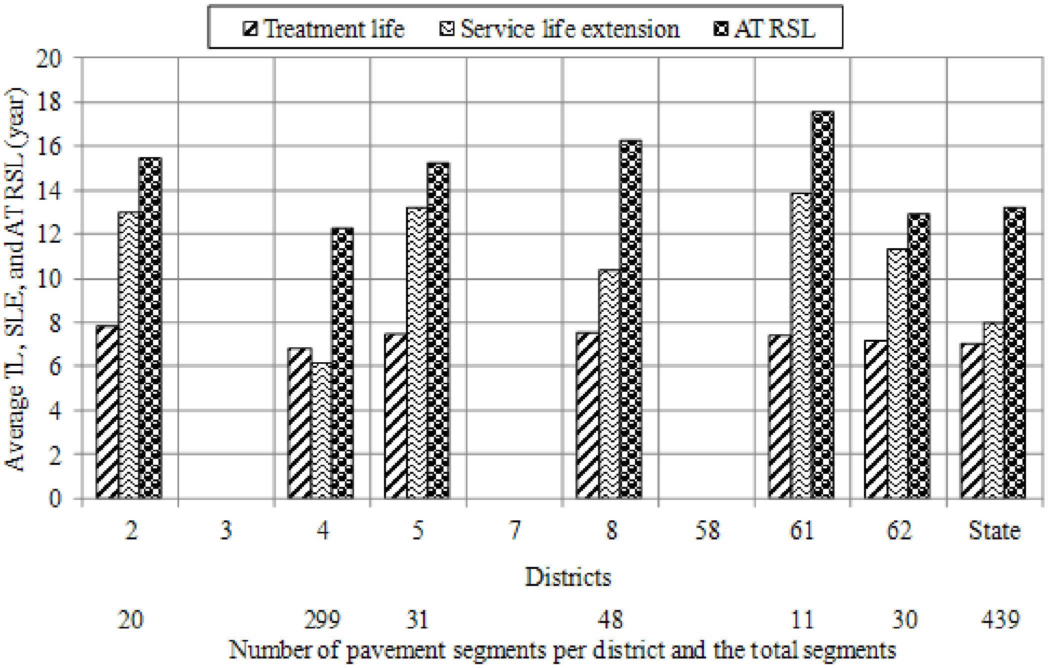


Figure 47

Treatment benefits for thin HMA overlay of asphalt surfaced pavement projects, all districts, state of Louisiana

Reset Value of Treatment

Introduction

Pavement will show improved condition once the treatment is applied; however, none of the treatments will return pavement to go back to its original construction value. The difference between pre-treatment condition and after-treatment condition is called condition jump.

Reset values are a function of type of treatment, type of distress, and functional classification. As an example, it is known that when overlay treatment is applied, all distress values (IRI, rut, and cracking) goes back to their original construction value. But chipseal, IRI, and rut do not go back to original condition, because chipseal cannot absolutely fix IRI and rut. All cracking become fixed after the application of overlay or chipseal.

Hence, the reset value of rut and cracking are assumed as 'zero' for overlay and replacement based on past experience and engineering judgment. The reset values for cracking are also assumed as “zero” for chipseal and micro surfacing. The IRI and rut resets are calculated (IRI cannot be “zero”) for all distress type in a specific way described below:

Current Practice of DOTD for Resets

Currently, DOTD is using Table 14 through Table 17 for determining the reset values for different treatment types and for different classification. DOTD uses Index value for Resets. Meaning of Resets used by DOTD:

- A100 – reset to absolute 100
- A0 – reset to absolute 0
- A92- reset to absolute 92
- R5- reset to relative 5 which means you add 5 to the current value but cannot go over 100.
- R10- reset to relative 10 which means you add 10 to the current value but cannot go over 100.
- N-1- N/A thus defaulted to -1

Determination of Reset Values for Overlay, Chipseal, Micro Surfacing and Replacement

Overlay and Replacement Treatments. From time series distress data, each project's IRI are plotted against time and best fit curve was used to determine the intercept (IRI value at "zero" year) as shown in Figure 48. The Figure 48 indicates that for this particular project the intercept value is 57.13in/mile. This intercept is the value of IRI just after treatment was applied and can be considered as Reset value. Hence, the average of all resets for all projects for a particular pavement type, functional classification, and thickness (Overlay) is calculated and recommended as Reset Value for said treatments. From past experience and engineering judgment, overlay, and replacements, IRI resets are not found as a function of previous IRI value before treatments.

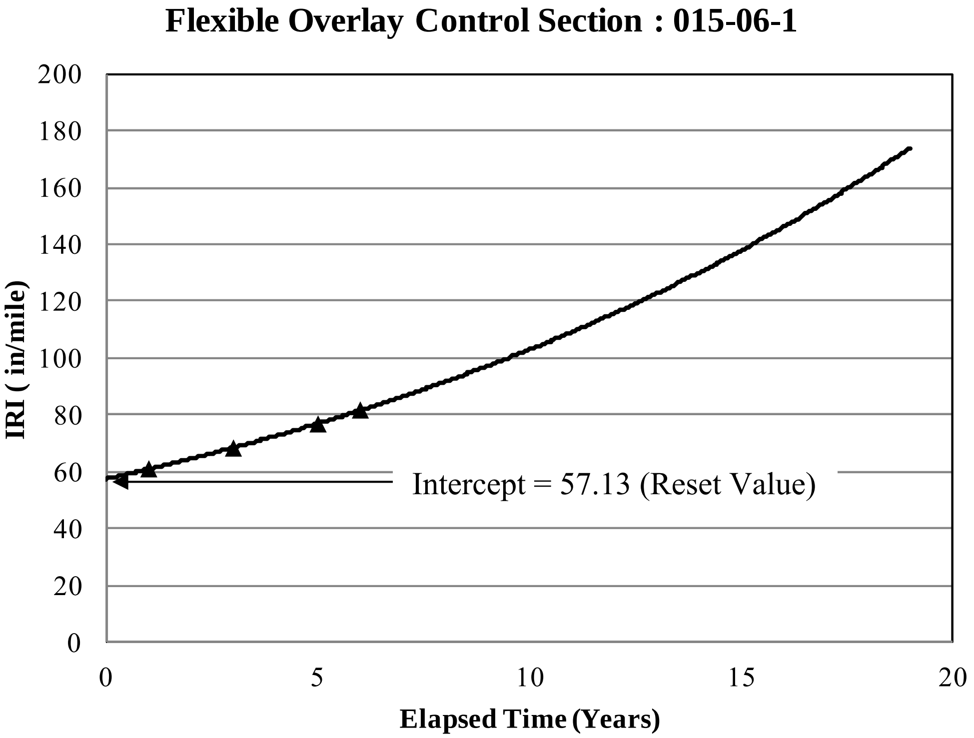


Figure 48
IRI after treatment as a function of treatment surface age

Chipseal and Microsurfacing Treatments. For chipseal and micro surfacing, IRI and rut intercepts values are calculated by similar technique as mentioned above. Further, for chipseal and microsurfacing, previous value of distress before treatment (IRIp) is found to be a function of the intercept of the distress just after treatment. Figure 49 shows that the intercept value of IRI just after treatment is strongly related with the IRI value just before treatment (IRIp). The coefficient of determination (R^2) between the two variables is 0.895. Recall that the intercept is defined as the Reset value: for chipseal and microsurfacing, the reset is a function of the IRI value just before treatment and can be represented by the following equation:

$$\text{Distress Reset} = a*(\text{Distress Value just before treatment}) + b \tag{22}$$

Where, a and b are regression constants.

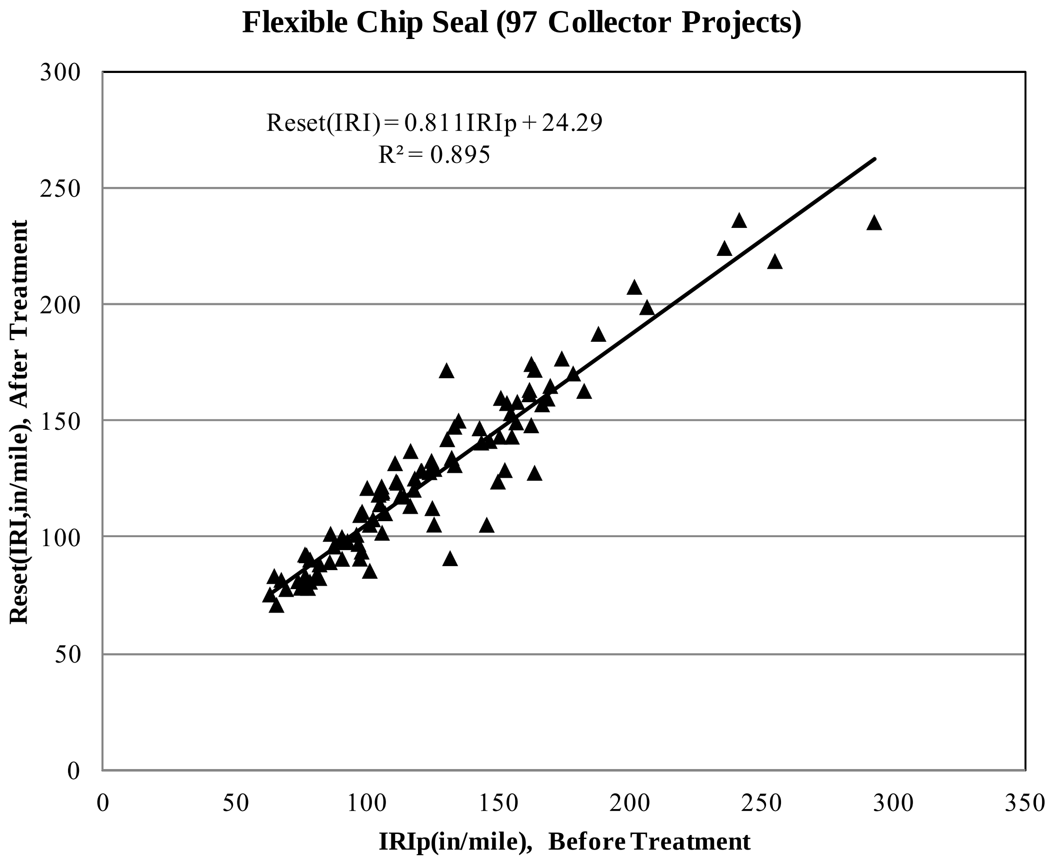


Figure 49
Relation between Reset value and IRIp for Chipseal Collector Projects (Flexible Pavements)

From Figure 49, it can be seen that for reset value of IRI distress for chipseal on flexible pavement for collector highway is represented by the following equation:

$$\text{Reset(IRI)} = 0.811*(\text{IRIp}) + 24.29 \quad (23)$$

Similar equations are developed for chipseal and microsurfacing for different functional classification for both rut and IRI. All the Resets for different treatment types are tabulated in and are present in the result section of this report.

Treatment Cost Benefit Analysis (TCBA)

Introduction and Background

A major factor in selecting the type of pavement for new construction or selecting a pavement treatment is cost. Sometimes, initial cost of a pavement may be low but the future maintenance and rehabilitation costs may be excessive and should be considered in the decision-making process. For an existing pavement requiring treatment, a treatment or a set of treatments might give better ride quality but at an exorbitant cost to the agency. To both avoid this type of situation and make the best possible decision for future construction and treatment application, two strategies are considered in this study.

- LCCA (Life Cycle Cost Analysis)
- TCBA (Treatment Cost Benefit Analysis)

Life Cycle Cost Analysis (LCCA)

LCCA is an economic evaluation method to compare alternatives that satisfy a need in order to determine the lowest cost alternative over a designated period of time. All the costs, including initial construction and future maintenances along with costs borne by the traveling public and overall economy in terms of user delay, are considered in the analysis. The Federal Highway Administration (FHWA) has always encouraged the use of LCCA in analyzing all major investment decisions. The current position of FHWA has evolved from ISTEA 1991, which required the consideration of life-cycle costing in the design and engineering of pavements in both metropolitan and state wide transportation planning. The NHS Designation Act of 1995 required states to conduct an LCCA for each proposed National Highway System (NHS) project segment costing $25 million or more. TEA-21 has since removed the requirement to conduct LCCA in transportation investment decision making, although, it is still recommended by FHWA to encourage the use of LCCA for National Highway System (NHS) projects *[15], [24], [25], [26], [27], [28]*.

Treatment Cost Benefit Analysis (TCBA)

For the existing pavements in Louisiana, DOTD did not do any kind of LCCA analysis and based their decision on existing design policy, experience, and engineering judgment. But the existing pavements constantly require maintenance and rehabilitation so an analytic approach named TCBA (Treatment Cost Benefit Analysis), which is similar to LCCA, is considered. The main goal of TCBA is to develop guidelines for the implementation of cost-effective pavement preservation strategies that would maximize the user and agency benefits and minimize their costs. There are similarities between TCBA and LCCA with only few exceptions. Definitions required to understand TCBA are given below.

Pavement Performance: Performance computation of a pavement is related to the behavior of the pavement condition indicators and the overall benefit associated with the application of a single treatment or a series of treatments. To simplify the computation, regular distresses of pavement are used rather than some custom-defined complex relationships.

Analysis Period: In TCBA, there is no pre-defined analysis period. The analysis period will vary depending on the selection of the treatment alternatives. The analysis period may be different for the same project based on treatment alternative. For a particular treatment alternative, the analysis period will be decided by the controlling distress. Any benefit area lost due to fixed analysis period will be utilized. Hence, the differences in analysis period will not hamper the evaluation procedure as benefit will be calculated in areas *[27]*.

Pavement Condition Indicator: Treatment has the ability to preserve or restore pavement condition and impede the rate of deterioration over time. This ability to change the condition of the pavement is the performance of the treatment. Evaluating the condition of pavement is done by assessing some pavement condition indicators. These pavement condition indicators should be quantitative rather than qualitative. For this research study, all the distresses are taken as the pavement condition indicator. The pavement condition indicators have the following properties *[15]*.

- Quantifiable (can be measures at a particular time)
- Performance indicator (the performance and the workability of the pavement is easily understandable)
- Prediction ability (can be predicted for future value with a suitable model)
- Improvement in indicator after applying a treatment

IRI, rut, fatigue cracking, transverse cracking, and longitudinal cracks are used as condition indicators in this study and all follow the above mentioned properties.

Do Nothing Analogy: The do-nothing situation is the progression of distress if no treatment is applied to the pavement. After the initial construction, pavement will reach its threshold value for reconstruction if no maintenance or treatment is applied close to its design period. In the Figure 50, we can see the do-nothing situation and the benefit achieved from the pavement.

After-Treatment Analogy: If a treatment is applied to the pavement before it reaches its threshold, the distresses will get reduced to the reset value of the treatment and the condition will improve. The pavement will now behave in a different way pertaining to the applied treatment. The shaded part in Figure 50 shows after treatment behavior for two different types of treatment and the benefit achieved form the pavement *[15]*.

Threshold Value: Threshold value for a distress refers to the condition of the pavement where no treatment is feasible and the only possible solution is to reconstruct the pavement. Threshold values might differ based on pavement type, functional classification and other criteria.

Treatment Trigger: Based on the optimum timing of treatment, trigger values for different types of treatments were established. Treatments should be applied when a trigger value has reached maximum benefit.

Reset Value of Treatment: Pavement will show improved condition once the treatment is applied. None of the treatments will return the pavement to its original construction value. The difference between pre-treatment condition and after-treatment condition is called *condition jump*.

Discount Rate: Discount rate is the interest rate by which future costs (in dollars) will be converted to present value. It is the percentage by which the cost of future benefits will be calculated to present value. Real discount rates reflect only the true time value of money without including the general rate of inflation which may complicate the analysis. Real discount rates historically ranged from 3% to 5% and for LCCA purposes, a value of 4% will be used *[15], [24], [25], [26], [27], [28]*.

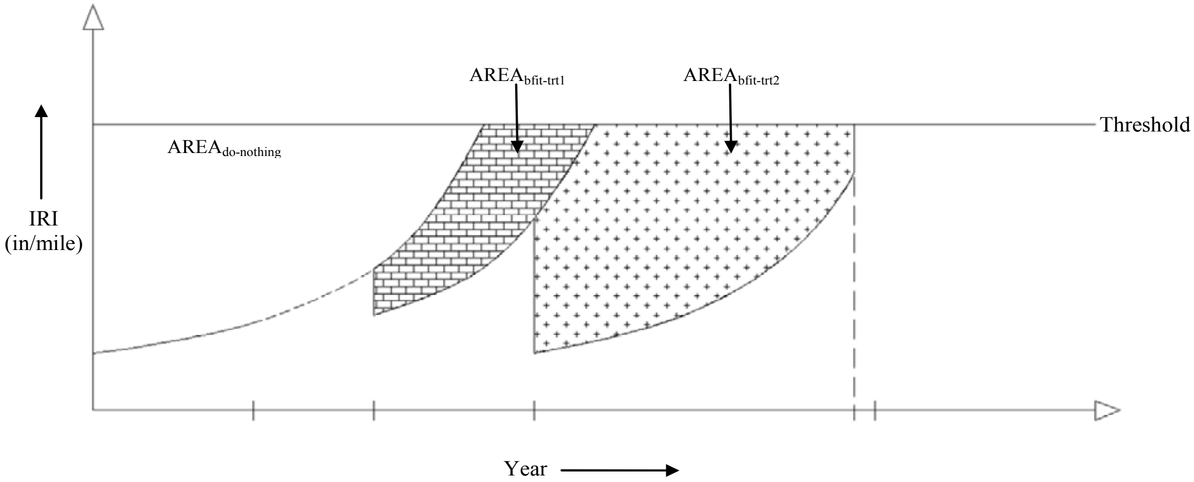


Figure 50
Illustration of do-nothing benefit and treatment benefit of a treatment.

Treatment Cost: Preventive maintenance is expected to delay the need for major rehabilitation. The cost of major treatment activity can be large in relation to the cost of a preventive maintenance treatment and the time to apply the treatment work can have a major impact on a pavement's overall lifecycle cost.

Maintenance Cost: All pavement types require preventive and corrective maintenance during their service life. The timing and extent of these activities vary from year to year. This cost includes all agency costs associated with the placement of a preventive maintenance treatment. These include design, mobilization, materials, construction, and traffic control costs.

User Cost: User costs are incurred by users of a roadway over the analysis period and can be expressed in monetary terms. User cost is generally associated with delays in the work zone during the application of treatment. There are three main categories of user costs:

- **Vehicle Operating Cost:** Costs related to consumption of fuel and oil, and wear on tires and other vehicle parts during normal operations. A normal operation is the time when the pavement is free of any kind of construction and operating in full capacity *[15], [25], [26], [27]*.
- **Work Zone Related User Delay Cost:** Costs due to reduced speeds for entering the construction zone or the use of alternate routes *[15], [25], [26], [27]*.
- **Crash Cost:** Costs occurred due to damage to the user's vehicle, other vehicles, and public or private property, as well as injury to the user and others *[15], [24], [25], [26], [27], [28]*.

Inclusion of user cost in LCCA is not applied by some highway agencies due to difficulties in estimating the cost which does not affect the agency directly. User cost can significantly affect the outcome of a LCCA to choose a design alternative.

Salvage Value: After analysis period, the pavement structure may have some remaining value to the managing agency as salvage value. The two components of salvage value are residual value and remaining service life *[27]*. Residual value is achieved by recycling the pavement after the end of its service life.

Cost Evaluation Method: The two most common methods used to evaluate treatment alternatives are the present value (PV) method and the equivalent uniform annual cost (EUAC) method. Each included treatment cost, user cost, or routine maintenance costs which are converted into present value (at current year) *[27]*.

$$P = V(1+i)^{-n} \tag{24}$$

Where, P= Present worth value of an included cost

V= Individual maintenance or rehabilitation cost (in actual dollars)

i= Discount rate

n= Year (since construction) where the individual cost is realized.

Then, the computed total present value could be used to get the equivalent uniform annual cost (EUAC).

$$EUAC = P_{Total}\left[\frac{i.(1+i)^{n_T}}{(1+i)^{n_T}-1}\right] \tag{25}$$

Where, P_{Total}= Total Present value of all included cost

i= Discount rate

n_T= Analysis Period

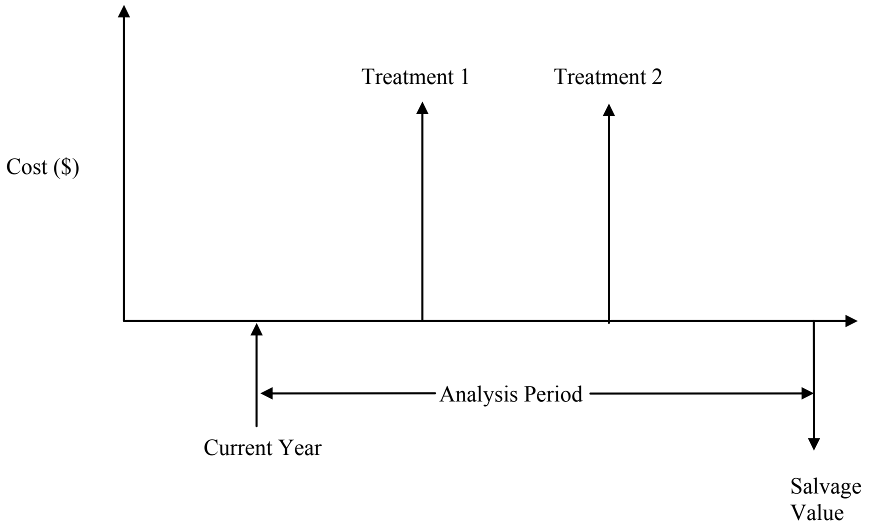


Figure 51
Cost estimation of TCBA approach

Proposed TCBA Approach

The procedural steps associated with conducting a Treatment Cost Benefit Analysis (TCBA) are:

Establish treatment alternatives (single treatment or a series of treatment) based on trigger values, reset values, remaining service life, life extension, engineering judgment, etc.

1. Life of a treatment alternative will be decided by the controlling distress
2. Estimation of cost including the following:
    - Treatment Cost
    - Maintenance Cost
    - User Cost
        - Vehicle Operating Cost
        - Work Zone Related User delay Cost
        - Crash Cost
    - Salvage Value
        - Residual (Recycle) Value
3. Establishing the discount rate
4. Calculate the cost (based on NPV or EUAC) for each considered alternatives

5. Calculate the benefit of the treatment alternative by applying area under the performance curve
6. Calculate the benefit cost ratio of each alternatives
7. Analyze and compare alternatives and rank the possible alternatives

Detailed Example of TCBA. Referring to Figure 52, a pavement is now in its current state in 8th year after initial construction and the agency wants to plan ahead for the future by making decisions about when and which treatment to use. All five distress models (IRI, rut, fatigue, transverse, and longitudinal cracking) are applied to predict the behavior of different distresses. In this example, IRI, rut, and transverse cracking (TC) are shown for the illustration of methodology. The pavement was constructed eight years ago so there are some distresses already prevalent in the pavement. From Figure 52, it can be seen that, after applying all the distress models, the IRI, rut, and TC reach their respective trigger values for applying chipseal treatment in 16, 17, and 14 years after the construction of pavement, respectively. Trigger values are denoted by $TR_{\text{Name of treatment}}$ in Figure 52 for illustration purpose. Based on trigger values, TC is the controlling distress if application of chipseal is an option. Say chipseal is applied to the pavement as a preventive measure at 14th year. A slight improvement in IRI and rut will be observed; however, TC will show a big condition jump exhibiting no crack value. After treatment application, performance models for chipseal will be used to predict the future behavior of the pavement. This time, distresses will be allowed to progress, until, say, a thick overlay trigger value is reached. After application of chipseal, it is found that IRI, rut, and TC reach their respective trigger values for applying chipseal in 24th, 22th, and 25th years, respectively. So, here, rut is the controlling distress for application of thick overlay at 22th year. Once the thick overlay is applied at pavement age of 22, all the distresses assume their respective reset values for thick overlay. After applying the distress models for IRI, rut, and TC to the pavement for thick overlay, it is found that IRI, rut, and TC reach their respective threshold values for reconstruction in 39th, 40th, and 38th years respectively. So, 17 years after application of thick overlay, the pavements need to be reconstructed if no treatment is applied. So, pavement will have an estimated life of 38 years considering these two treatments.

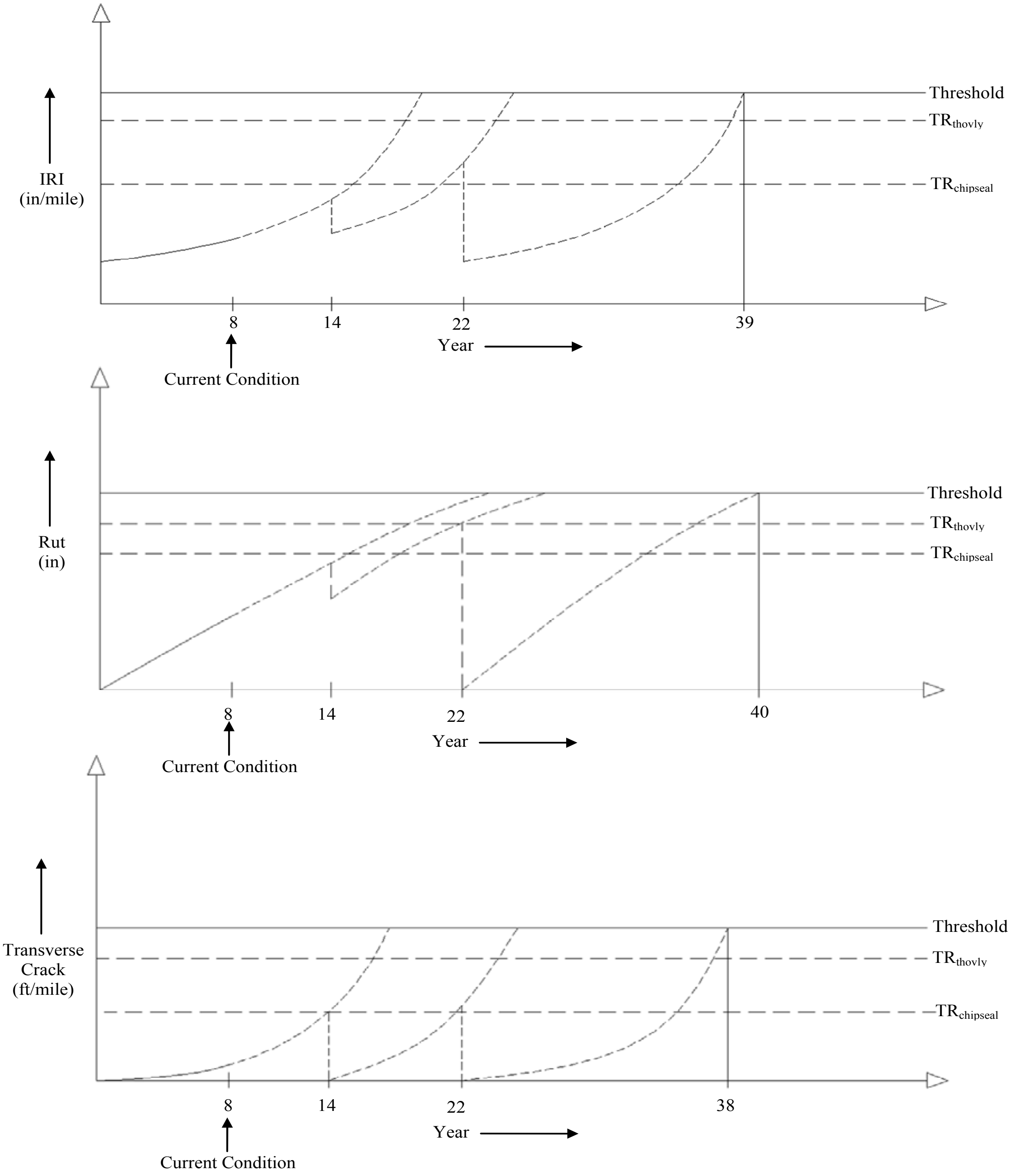


Figure 52

Treatment application for controlling distresses and trigger values

Procedure for TCBA (Treatment Cost Benefit Analysis)

- Only the benefits resulting from the treatments will be taken into consideration. Pavement is already constructed so initial construction cost and the initial benefit to the pavement will not be considered in the analysis.
- Various combinations of treatments can give different life of the treatments; each combination should be analyzed based on its life. In the given example, analysis should be done for 38 years.
- After application of chipseal in the 14th year, AREA $_{\text{bfit-trt1}}$ was benefit achieved by 1st treatment (chipseal in this case) as shown in the Figure 53, if no other treatment was applied.
- After application of thick overlay in 22nd year, 17 years of life was observed. Here, AREA$_{\text{bfit-trt2}}$ was the benefit achieved by 2nd treatment (thick overlay in this case) which is also shown in Figure 53.
- Agency will incur cost of chipseal treatment at (14-8) = 6 years from now and thick overlay treatment at (22-8) = 14 years from now.
- User cost will also happen during the application of both the treatments.
- All the costs will be converted into present year (which is 8th year after the initial construction)
- All the areas are curtailed at 38th year to ensure that all computed benefit areas for the included condition indicators use the same analysis period.
- Five condition indicators have four different units (transverse and longitudinal crack have same unit). So, converting individual condition indicator benefit areas into one overall benefit value becomes quite difficult. To solve this difficulty, each individual condition indicator is normalized by dividing by its associated threshold value. By doing that the threshold becomes one and the benefit area is bound within 0 to 1 in y-axis, thus making it easy to convert individual condition indicator benefit areas into one overall benefit area (see Figure 54).
- After normalizing benefit areas for each condition indicator, benefit areas for all the condition indicators will be calculated using discreet area trapezoidal method.
- Total present cost will be divided by the summation of total normalized benefit area to get the cost-benefit ratio.
- Calculation of cost-benefit ratio of various combinations of treatments will be done and presented based on rank.

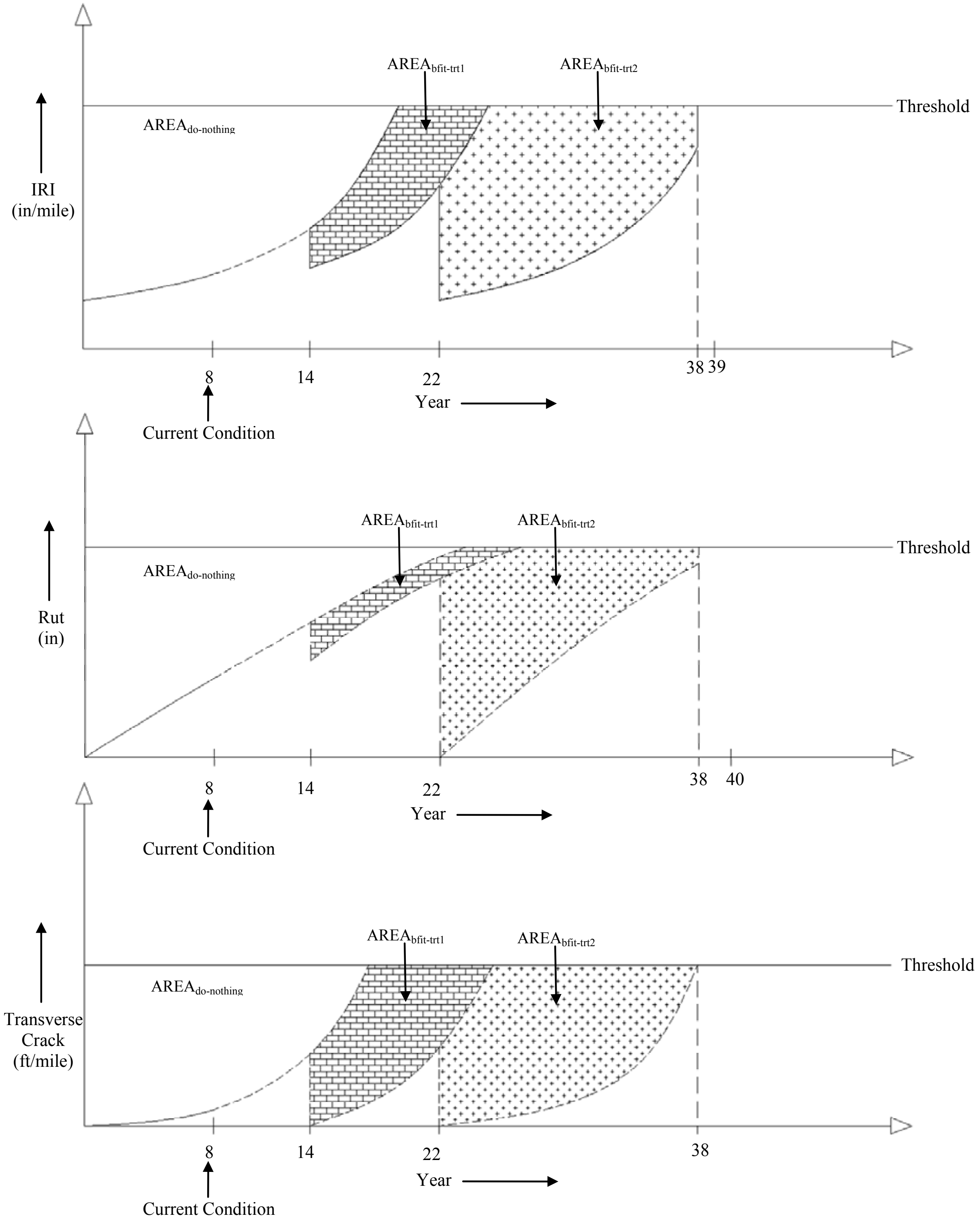


Figure 53

Treatment benefits and do-nothing benefits

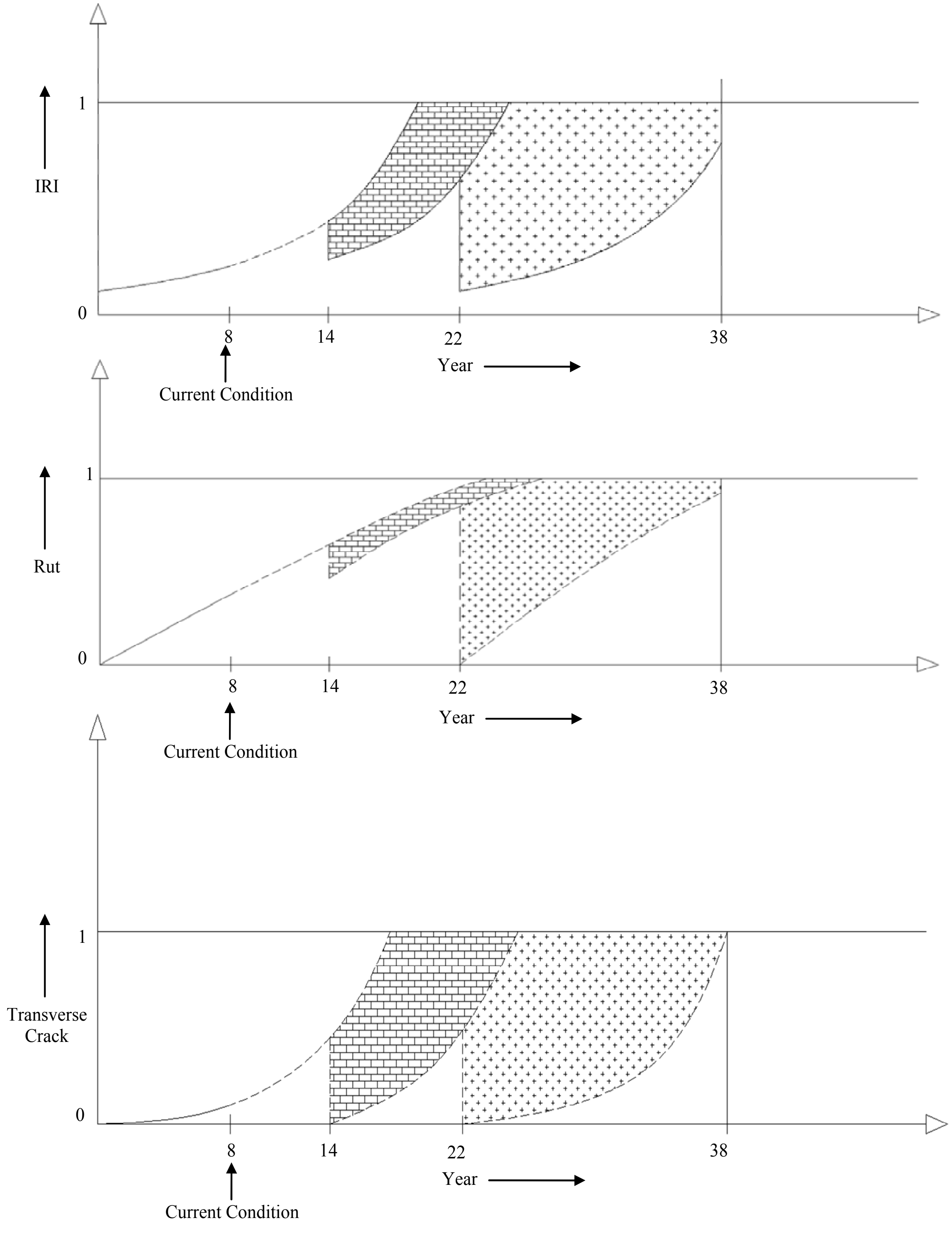


Figure 54

Normalizing the treatment benefits

DISCUSSION OF RESULTS

Review of District's Pavement Treatment Practices

Results of District Survey 2011

A survey questionnaire was mailed to all districts of the DOTD and for convenience it is included in Appendix B of this report. Six districts (02, 03, 05, 08, 61, and 62) responded to most questions while three (04, 07, and 58) did not respond to any questions although they were contacted on multiple occasions and were offered assistance in completing the survey. The responses from the six districts were analyzed and the results are summarized below. It should be noted that, in this document, the term "all districts" refers only to the six districts who returned the survey.

Section A-General. Figure 55 depicts a summary of the district responses regarding the yearly percent of the District's lane-miles that receive various pavement treatments. These include:

- District 02 - About 4.45% of the state lane miles receives non-structural overlay (≤ 2 in) treatment and only 0.24% receives ultra-thin overlay treatment.
- District 03 – About 1.08% of the state lane mile receives replacement treatment and only 0.07% receives non-structural overlay (≤ 2 in.).

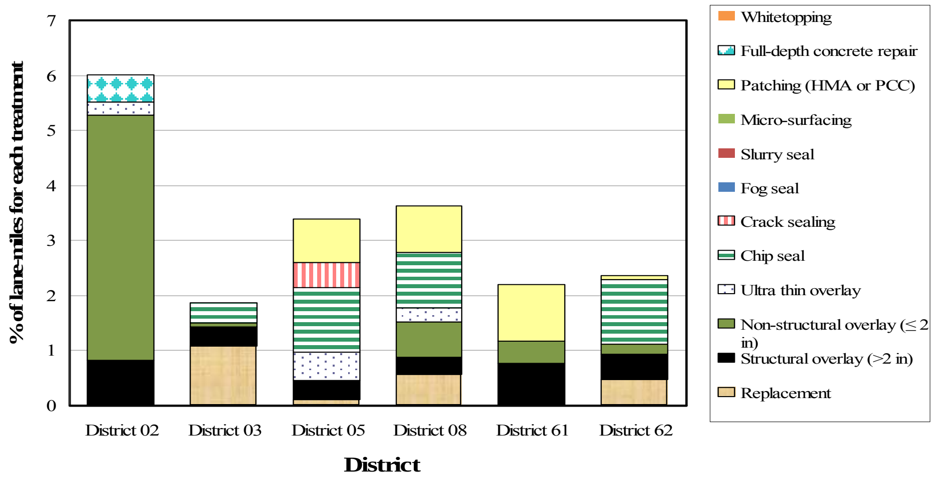


Figure 55
The percentages of lane-mile in various Districts that receive various treatments

- District 05 – About 1.18% of the state lane mile receives chipseal treatment and only 0.11% receives replacement treatment.
- District 08 - About1.08% of the state lane mile receives chipseal treatment and only 0.25% receives ultra-thin overlay treatment.
- District 61 - About 1.02% of the state lane mile receives patching treatment and only 0.41% receives non-structural overlay (≤ 2 in) treatment.
- District 62 – About 1.17% of the state lane mile receives chipseal treatment and only 0.07% receives patching treatment.

The six districts responses also included the cost and the benefits of each treatment. The information is summarized in Table 51.

Section B- Pavement and Mixture Design. In the state of Louisiana, pavement design for all districts are conducted by Jeff Lambert, the head of the Pavement Design section located in the headquarter of DOTD. Hence, he was requested to complete Section B (pavement design section) of the survey questionnaire. His responses are summarized below.

- The districts design the pavement mixtures.
- The districts do not design the pavement thickness or the thicknesses of treatments.
- Replacement and Structural overlay (>2 in) are designed based on only the AASHTO procedure. Non-structural overlay (≤ 2 in) is designed based on the AASHTO procedure coupled with in house experience.
- For PCC treatments such as all HMA overlay thicknesses are designed based on the HMA Superpave mix design procedure. PCC bonded and unbonded overlays are designed using the PCA and ACI procedures and the volumetric mix design procedures.
- For HMA treatments like replacements, HMA structural overlay (>2), HMA non-structural overlay (≤2) are designed based on HMA Superpave mix design procedure.
- White topping are designed by using PCA and ACI design methods.

Section C- Project Scoping Process. Nearly all districts (5 out of 6) use the PMS data in their project scoping process. Only District 5 reported that they do not utilize the PMS data.

The six districts use various methods and available data to evaluate the existing pavement conditions including distress data, composite pavement index, visual survey, remaining service life and so forth. The degrees to which the methods are used are depicted in Figure 56.

Table 51
Cost and benefits of various treatments (DOTD survey)

Treatment type	Cost per lane mile ($)			Benefits (year)			Average cost to benefit ($/lane-mile/year)
	Maximum	Minimum	Average	Maximum	Minimum	Average	
Replacement	325,000	275000	301000	20	10	16.7	18024
Structural overlay (> 2 in.)	275000	117000	215400	15	7	10.6	20321
Non-structural overlay (≤ 2 in.)	190000	100000	157500	14.5	7	9.8	16071
Ultra-thin overlay	93000	15000	40750	12.5	6	9.25	4405
Chipseal	9400	9400	9400	6.5	4	5.25	1790
Crack sealing	No cost data reported			4	3	3.3	-
Fog seal	No cost data reported			7	5	5.75	-
Slurry seal	No cost data reported			No benefits data reported			-
Micro surfacing	75000	16000	45500	7	5	6	7583
Patching	60000	10000	35000	7	5	5.75	6087
Full depth concrete repair	116000	95000	105500	7	7	7	15071
White topping	No cost data reported			No benefits data reported			-
Others	No cost data reported			No benefits data reported			-

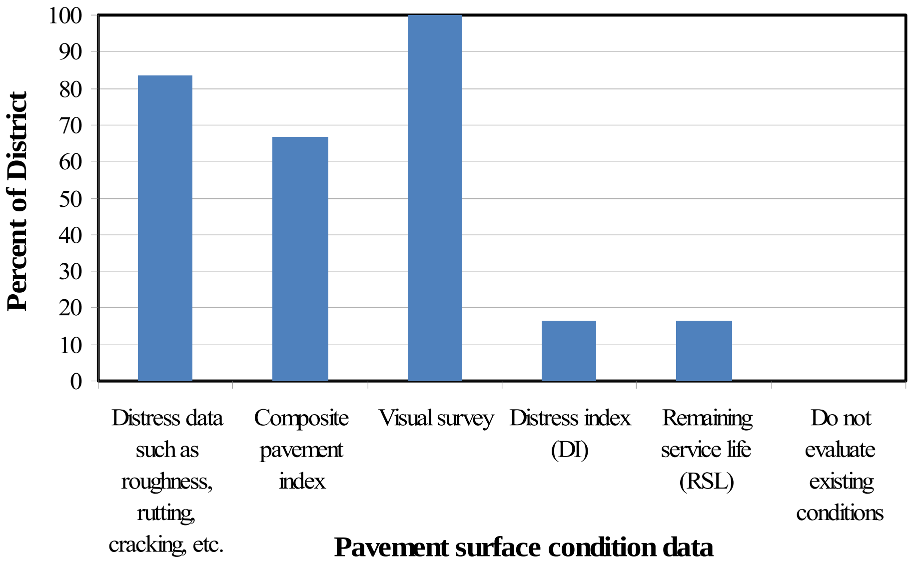


Figure 56
Methods used by districts for project scoping process

It was stated that the reasons for treatment selection are to improve ride quality (6 districts out of 6), improve skid resistance (5 of 6), eliminate surface rutting (5 of 6), retard distress propagation (4 of 6), improve structural capacity (4 of 6), political (3 of 6), and provide a wearing surface (2 of 6).

The allocations of the district yearly budget to the different treatment types are depicted in Figure 57 and Figure 58. It can be seen that districts 02 and 61 allocate, respectively, 83 and 84% of their yearly budget to pavement rehabilitation. On the other hand, the other four districts allocate less than 50% to the same. The overall budget allocation consists of 49% for rehabilitation and only 6% for routine maintenance.

All six districts do not use trigger values in their treatment decision making processes. However, five of the six districts use some of the PMS data in multiple forms to evaluate their projects. For example:

- In the initial step of their evaluation proves, District 02 and District 03 use, respectively, IRI values of 100 and 200 inch/mile to filter their projects.
- Districts 08, 61, and 62 use the PMS data with an emphasis on IRI in their project ranking procedure.
- District 05 does not use PMS data in their decision making process.

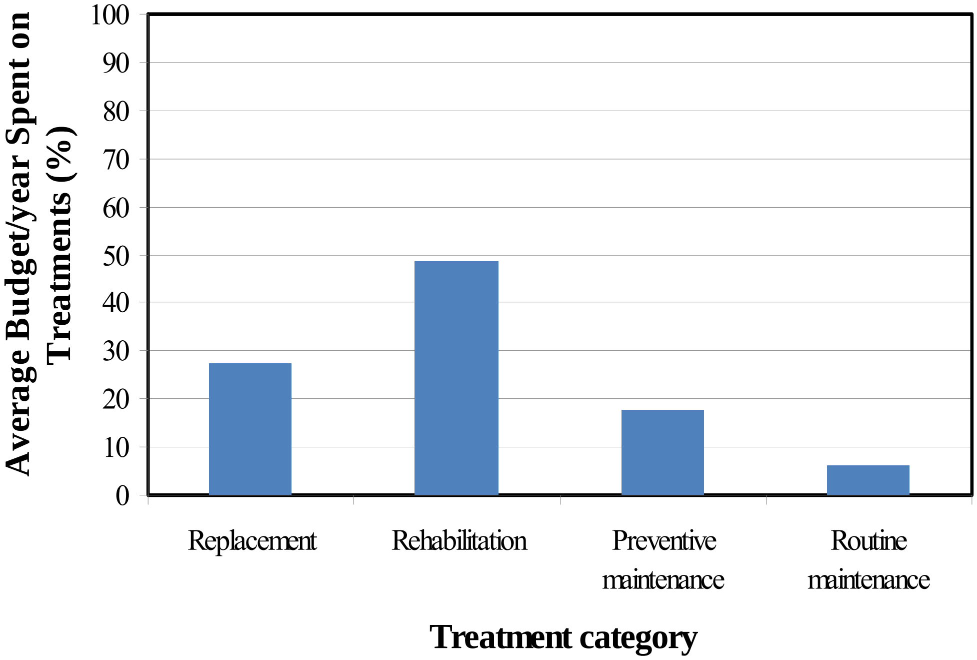


Figure 57
Yearly district budget spent on pavement treatments.

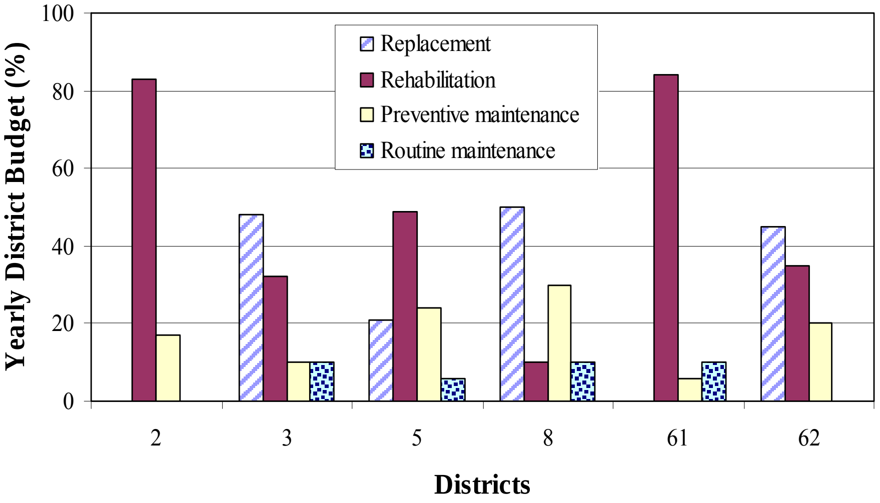


Figure 58
Yearly budget allocations of the six districts

Only District 08 uses Remaining Services Life (RSL) in their decision making processes. The other districts use RSL in their project ranking.

Various pre-treatment repairs are applied for pavement preservation, including:
- Continuous milling
- Patching
- Crack sealing
- Cold patching
- Rubblizing
- Spot milling

For structural overlays (>2 in.) continuous milling and patching is dominant. However, for non-structural overlays (≤ 2 in.) patching is dominant. In the case of ultra-thin overlays, patching and crack sealing are used. For chipseal only, patching is used as a pre-treatment repair while spot milling and cold patching are used before micro-surfacing.

Section D- Traffic. The data displayed in Figure 59 and Figure 60 indicate that reduced speeds, interim pavement markings and devices, and flaggers are the primary traffic control measures being used by all districts. However, pilot vehicles, detours, and temporary traffic control devices (traffic lights) are being used by the districts for only a few pavement treatments.

For the most part, no district restricts pavement treatment type selection based on minimum or maximum ADT level. The exceptions to these restrictions are:

- District 03, maximum ADT of 7,000 for chipseal
- District 61, maximum ADT of 1,000 for chipseal
- District 62, maximum ADT of 2,5000 for chipseal
- District 05, minimum ADT of 400 for replacement and structural overlay.

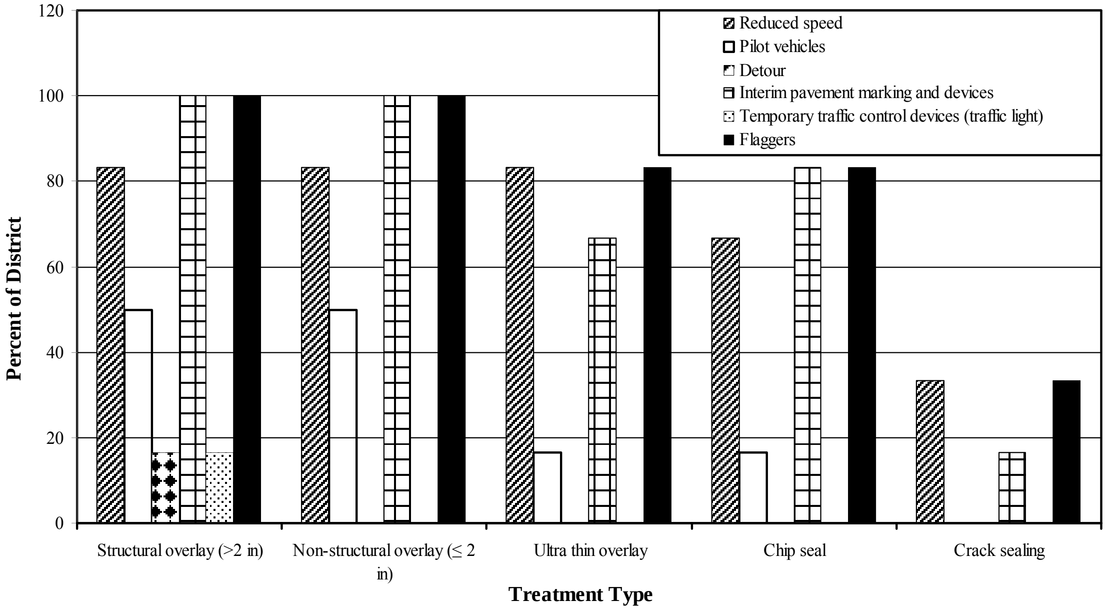


Figure 59

Use of traffic control devices by District for pavement treatments including structural and non-structural overlays, ultrathin overlays, chipseal and crack sealing.

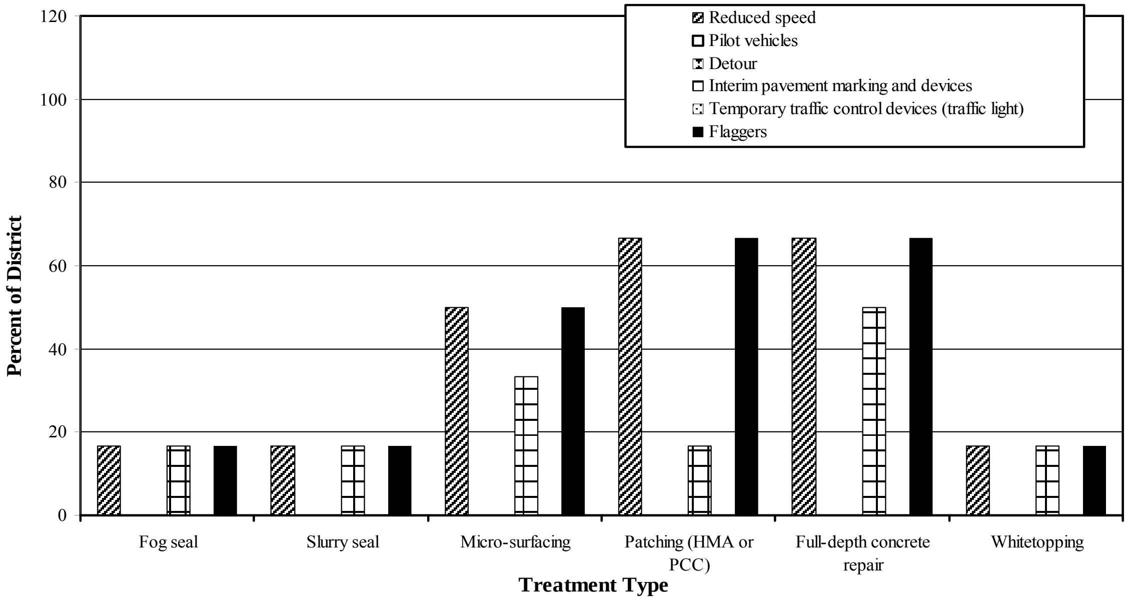


Figure 60

Use of traffic control devices by District for pavement treatments including fogseal, slurryseal, microsurfacing, patching, full depth concrete and whitetopping.

Section E- Contracting and Costs. The results of the survey indicate that the time needed for completion of rehabilitation treatments could require anywhere between 3 to 24 months for each design and construction phase of the project. Details of the required time for various treatments, as well as contractor response, are outlined below.

- For pavement preservation treatments, the required time for each phase (design and construction) is 2 to 18 months.
- For structural pavement treatment (rehabilitation) projects, the typical number of contractors that bid on district projects ranges from 4 to 6. District 02 reported, though, that 1 to 3 contractors bid on their projects.
- For pavement preservation treatment projects, the typical number of contractors that bid on district projects ranges from 4 to 6. District 02 reported that 1 to 3 contractors bid on their projects while District 61 stated that 7 to 9 contractors submit bids for their projects.
- All districts, with the exception of District 02, feel that an adequate number of experienced contractors bid on their projects. This can be seen in Figure 61.

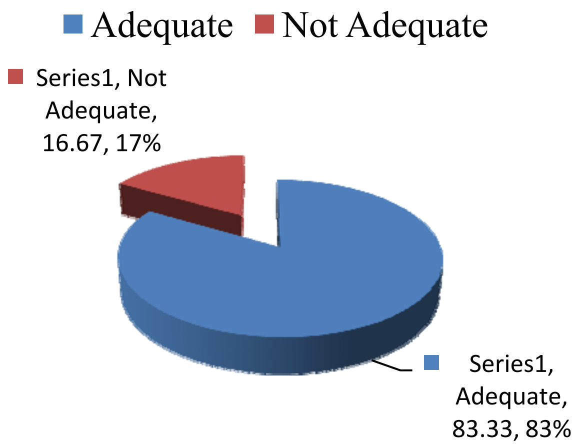


Figure 61
District opinion on adequate number of contractors bidding the pavement treatment jobs

Most pavement treatment types are used year-round with some districts refraining from construction during the winter. All districts, though, stated that concrete patching was a year-round project. Finally, no districts use Life-Cycle Cost Analysis (LCCA) in their decision-making process.

Section F- Performance and Evaluation. Figure 62 displays the responses of the districts regarding which are considered to be the most important factors affecting pavement defects and extending treatment life. The results are summarized below:

- Five of six districts consider construction procedure and the underlying structure to be the most important.
- Three of six districts consider moisture damage to be the most important.
- Two of six districts consider quality control and maintenance spending to be the most important.
- Only one district considers traffic to be the most important.
- No district considers aggregates or binders, design methods, or friction to be important factors in minimizing pavement defects and extending the life of the treatments.

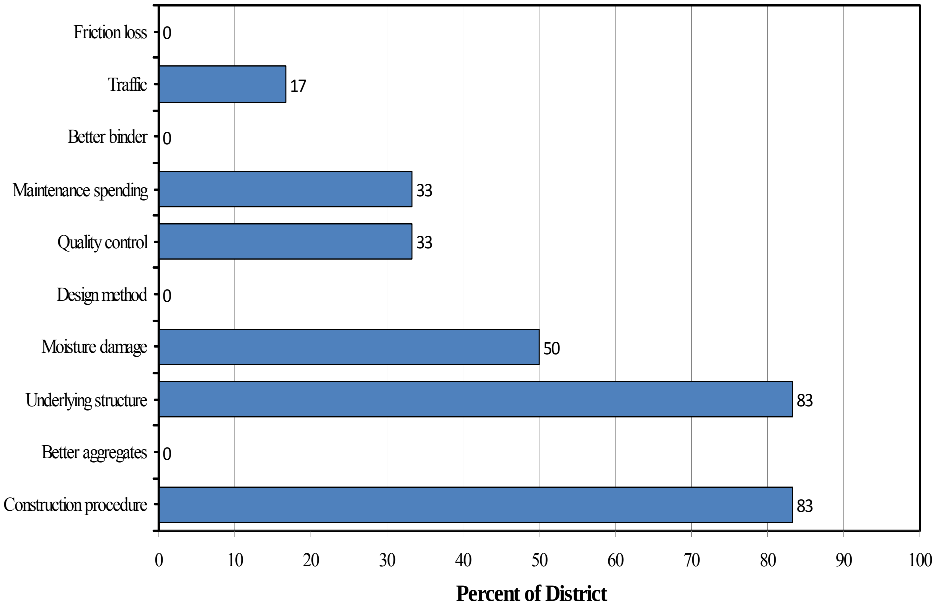


Figure 62
District responses regarding factors that minimize pavement defects

Several types of distress occur after the application of each treatment type. The ranking of dominant distress types occurring after application of each of the treatments is listed in Table 52. The ranking of 1 implies the most dominant distress type. Following is the overall district summary of dominant distress ranking after treatment.

- For replacement: mostly alligator, transverse, and longitudinal cracking. Some raveling, potholes, and rutting.
- For structural overlay (>2 in.): mainly alligator, transverse, and longitudinal cracking with some potholes, rutting, raveling, and corrugation.
- For non-structural overlay (≤ 2 in.): alligator, transverse, and longitudinal cracking with some rutting. Few faulting and raveling.
- For ultrathin overlay: cracking, raveling, and potholes.
- For chipseal : alligator, transverse, and longitudinal cracking with some corrugation and potholes (only 2 districts reported).
- For microsurfacing: mainly bleeding and raveling.
- For HMA or PCC patching: mainly faulting, corner break, and rutting
- Full-depth concrete repair: faulting, corner break, and transverse cracking were dominant.
- Whitetopping: mainly faulting and corner break.

Table 52

Ranking of treatment based on dominant distress types occurring after application of each of the treatments (a ranking of 1 is the most dominant)

Treatment Type	PH	BL	CR	RV	AC	TC	LC	RT	FT	CB
Replacement	4.7	10.0	5.3	4.3	3.2	3.3	2.8	3.7	6.0	7.0
Structural overlay (>2 in)	5.0	8.5	4.7	4.7	3.8	2.3	2.5	2.5	8.5	9.5
Non-structural overlay (≤ 2 in)	4.0	8.5	4.7	3.7	3.0	2.3	3.0	2.3	8.5	9.5
Ultra thin overlay	4.0	6.3	6.5	3.0	2.5	2.5	4.0	2.5	8.5	9.5
Chipseal	6.0	4.3	3.0	4.3	3.0	2.5	2.5	7.5	8.5	9.5
Crack sealing	6.0	2.0	7.0	1.0	5.0	4.0	3.0	8.0	9.0	10.0
Fog seal	2.0	3.0	4.0	1.0	5.0	6.0	7.0	8.0	9.0	10.0
Slurry seal	2.0	3.0	4.0	1.0	5.0	6.0	7.0	8.0	9.0	10.0
Micro-surfacing	-	1.0	-	2.0	-	-	-	-	1.0	2.0
Patching (HMA or PCC)	9.0	10.0	8.0	7.0	6.0	5.0	4.0	2.0	1.0	2.0
Full-depth concrete repair	8.0	10.0	7.0	6.0	5.0	4.0	3.0	9.0	1.0	1.7
Whitetopping	9.0	10.0	8.0	7.0	6.0	5.0	4.0	3.0	2.0	1.0

PH: potholes; BL: Bleeding; CR: Corrugation; RV: Raveling; AC: Alligator Cracking; TC: Transverse Cracking; LC: Longitudinal Cracking; RT: Rutting; FT: Fatigue Cracking; CB: Corner Break

As it can be seen in Figure 63, for most treatment types, the districts have varying opinions on the ride quality before and after treatment. However, replacement, structural overlay, non-structural overlay, and ultra thin overlay are mostly considered to provide better ride quality after construction.

No district subcontracts quality assurance works were also reported by the districts.

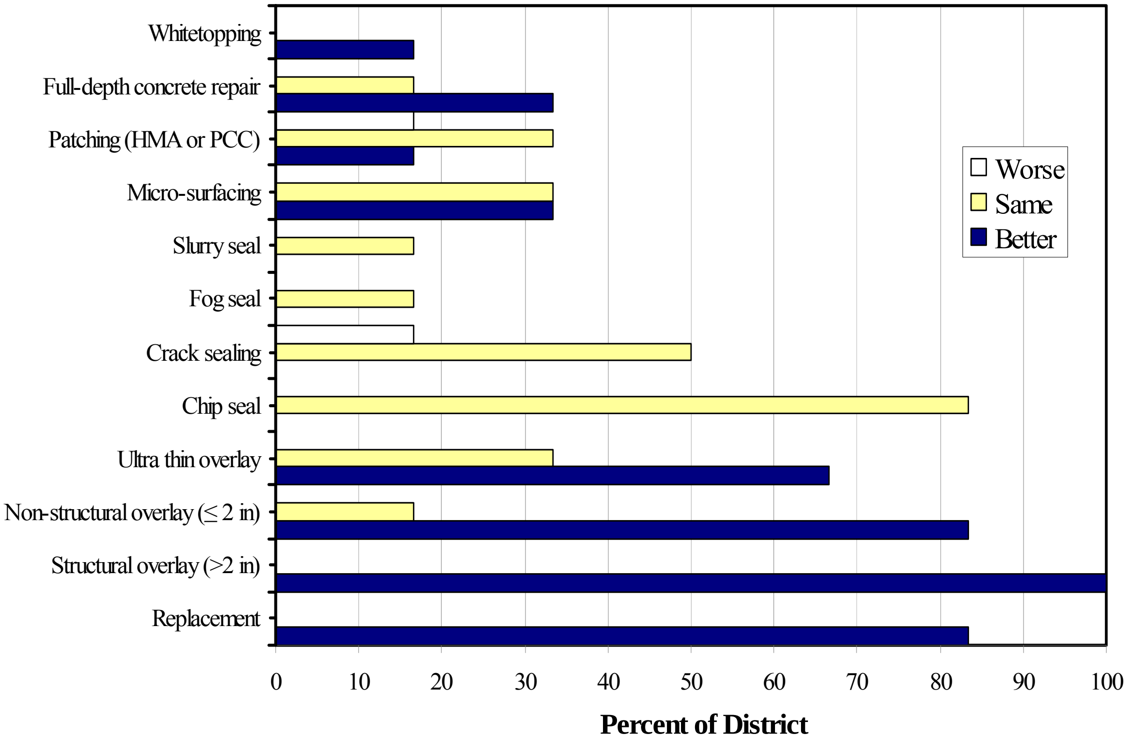


Figure 63
District results for ride quality after the treatment compared to before treatment.

Summary of Comments from District. The following text summarizes comments from various Districts regarding topics that were not specifically covered in the survey.

District 05: Melvin Hicks is developing a GIS map showing past construction, proposed future construction, roads that are left along with their condition, vehicle miles traveled, and proposed treatments from PMS, to offer to Area Engineers as a tool to develop priority lists for projects for future years. He also stated that, currently, projects are being solicited without having the benefit of being aware of the condition of the system as a whole. He does not believe that they are effectively utilizing the information available at the district level. He wants to be able to generate maps from which data can be queried that allow choosing the most beneficial method of distributing funds for the various programs that they have for funding.

District 08: Robert Mays (ADA) stated that the current District Administrator (DA) has a process (program) in place that analyses PMS data, in some sort, that helps with the project selection process. The DA developed this process when he was employed as the head Design Engineer in District 08 over 10 years ago.

District 61: Ronnie Robinson wanted to note that he believes that Area Engineers are a big key in regards to the decision making process of selecting treatments. He stated that the Area Engineers will initiate the notification to him of all specific roadways that is in need of treatment within their parishes.

District 62: Jesse McClendon expressed some concern about soil cement material causing an increase in cracking in areas of high truck volume. He wants to shift pavement rehabilitation toward in-placed stabilized base material.

Selected Pavement Treatment Projects

Summary of Treatment Projects

Based on the methodology adopted for pavement treatment project selection, about 972 projects were initially identified on which some type of pavement treatment was applied. It was found that approximately 791 treatment projects had good performance and historical data. These projects have three distress data points before and three data points after the application of treatment. In addition to this, around 1203 projects were identified that had one distress data points before and three or more data points after the treatment. Tables in Appendix C provide the overall distribution of selected projects based on treatment type, distress type, and districts. It should be noted that for each project, a comprehensive data search was conducted to acquire historical data, traffic data, pavement type and classification, and pavement performance data. The data were summarized in a tabular format and are detailed in Appendix C. An example of such summary is also shown in Table 53.

It was found that sufficient pavement treatment projects are available for overlay and chipseal treatments followed by pavement replacement. However, for other treatment types, fewer projects were found with adequate historical and performance record. The data also indicate that the percentage of accepted 1/10th mile sections for three data points BT and three data point AT for each treatment and pavement type ranged from 22 to 86%. However, the percent acceptance increases (ranging from76 to 100%) for 1 BT and 3 AT data points. This implies that there is substantial variability for the pavement performance data before the application of pavement treatments.

Table 53
Example summary of candidate projects (continued)

Control Section	Project No	BLM	ELM	Average ADT for treatment year	ADT-2003	Average Annual Traffic Growth	Calculated EALA	Functional Classification Code	K_ factor	Parish	% Trucks
051-03-1	051-03-0028	0.2600	4.9200	3,988	2,800	3	18,396	06	11.0	21	10.0
065-30-1	065-30-0028	3.6900	6.3400	20,155	25,100	1	186,520	16	10.0	55	10.0
073-04-1	073-04-0012	0.0900	5.3300	831	940	1	4,048	09	10.0	40	4.0
126-01-1	126-01-0020	0.0000	6.0000	936	1,280	1	4,141	07	10.0	64	4.0
133-03-1	133-03-0011	4.5000	8.7490	-	480	1	9,275	07	10.0	58	14.0
191-02-1	191-02-0010	0.0000	8.4500	434	690	1	10,616	08	12.0	6	21.0
374-03-1	374-03-0019	0.0000	4.0000	614	580	1	566	09	10.0	5	6.0
424-08-1	424-08-0026	7.3600	8.9000	-	21,300	1	187,155	02	8.0	29	11.0
424-08-1	424-08-0026	8.9000	11.8300	-	21,300	1	189,709	02	8.0	29	11.0
424-08-2	424-08-0026	7.3600	7.6000	20,881	21,300	1	187,155	02	8.0	29	11.0
424-08-2	424-08-0026	7.6000	8.1000	20,881	21,300	1	187,155	02	8.0	29	11.0
424-08-2	424-08-0026	8.1000	11.8300	20,881	21,300	1	189,161	02	8.0	29	11.0
826-14-1	826-14-0012	0.4400	0.9900	-	460	1	1,106	19	12.0	26	5.0
826-15-1	826-15-0010	0.0000	0.4800	-	6,000	2.9	14,426	17	12.0	26	5.0
826-16-1	826-16-0012	1.2600	1.6100	-	6,000	2.9	14,426	17	12.0	26	5.0
826-51-1	826-51-0002	0.0000	0.0500	-	460	1	1,106	19	12.0	26	5.0
835-06-1	835-06-0016	4.0300	6.3300	-	2,200	3	1,710	08	10.0	35	-
846-11-1	846-11-0005	0.0000	5.7300	-	350	1	3,330	09	12.0	46	14.0

Treatment Performance Models and Behavior

For composite, flexible, and JCP pavements, pavement distress prediction models were developed for overlay, chipseal, and microsurfacing treatments. The following section provides the discussion of various developed models.

Composite Pavement with Overlay Treatment

International Roughness Index (IRI) Model. Based on the methodology adopted for pavement treatment project selection, about 931.3 km (578.7 miles) of composite pavements were initially identified for composite pavement where HMA overlay treatment was applied. However, some of the projects lacked necessary data and after further scrutinizing, 78 projects were selected, comprising 451.5 km (280 mile) of composite pavement. Regression analysis was conducted and the following model was developed.

$$\ln(IRI) = a_0 + a_1 * \frac{\ln(CESAL)}{(T_{HMA} / T_{PCC})} * Fn + a_2 * \ln(IRI_p) + a_3 * CTI * t + a_4 * PI + \Delta \tag{26}$$

Where, IRI unit equals in/mile, IRI_p equals IRI value before treatment, CESAL equals cumulative ESAL, which can be calculated using the following equation:

$$CESAL = ESAL_i \left(\frac{(1+r)^t - 1}{r} \right) \tag{26a}$$

$ESAL_i$ equals Initial ESAL, r equals ESAL growth rate, T_{HMA} equals thickness of HMA overlay, T_{Pcc} equals thickness of PCC layer, Fn equals functional classification, CTI equals cumulative temperature index (Degree Fahrenheit-days), t equals age of treatment (year), PI equals precipitation index (in-days) and

$\Delta = -1.514 + 0.310 .ln(SD_o) + 0.362 .ln(IRI_{PP}) .$

Where, SD_0 equals Initial standard deviation (15.4 in/mile for composite pavement, based on this study) and IRI_{pp} equals predicted value of IRI of the previous year. After the regression, the final form of the IRI was found to be:

$$IRI = \exp\left[\begin{array}{l} \alpha * (1.893 + 0.0015 * \dfrac{\ln(CESAL)}{(T_{HMA} / T_{PCC})} * Fn + 0.273 * \ln(IRI_p) \\ +1.23 * 10^{-6} CTI * t + 1.36 * 10^{-5} PI + \Delta) \end{array} \right] \tag{27}$$

Where, α equals 1.008 is a calibration factor obtained by minimizing the RMSE value using the above model.

The results of statistical analysis are shown in Table 54. Figure 64 shows the predicted versus the measured ln(IRI) values for overlay treatment on composite pavement. It depicts that, with an exception of a few data points, there is a good agreement between the predicted and measured IRI values, thus indicating that the model was able to predict the IRI reasonably well. Similarly Figure 65 illustrates the model behavior for few selected projects. From Figure 66, we can see that the error distribution of IRI is normal with an indication of good applicable model. Also, as from the Table 54, it is clear that all the variables are statistically significant at p-value ≤0.05.

Table 54

Statistics of the regression analysis of IRI model for composite pavement

Regression Statistics				
Multiple R			0.79	
R Square			0.63	
Adjusted R Square			0.62	
Standard Error			0.254	
Observations			280	
F-statistics			91.88	
Significance-F			$1.6x10^{-56}$	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	1.892	0.2042	10.20	0.00
a_1	0.00151	0.0004	3.50	0.00
a_2	0.2727	0.0391	6.98	0.00
a_3	$1.23x10^{-06}$	$1.0x10^{-06}$	2.17	0.03
a_4	$1.36x10^{-05}$	$2.8x10^{-06}$	1.93	0.05

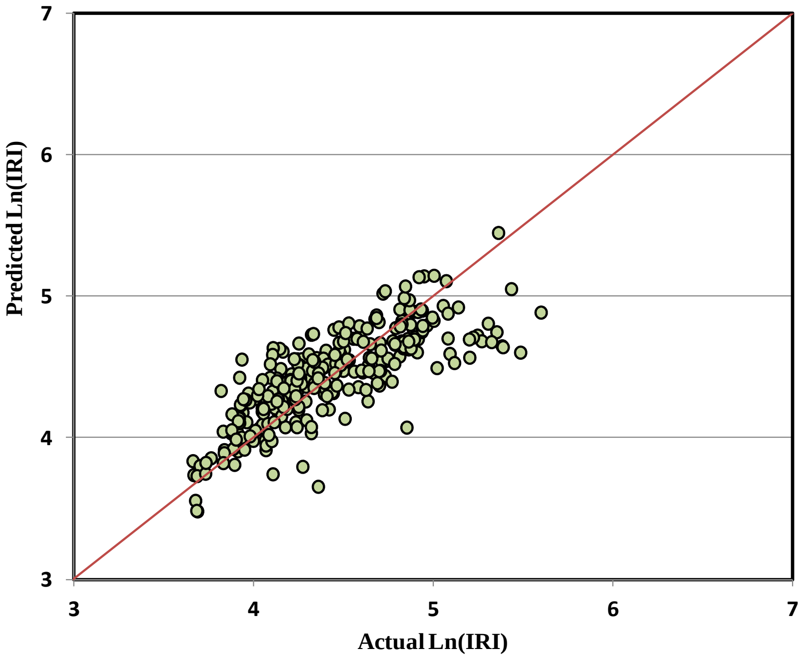


Figure 64

Predicted versus actual ln(IRI) for composite pavement

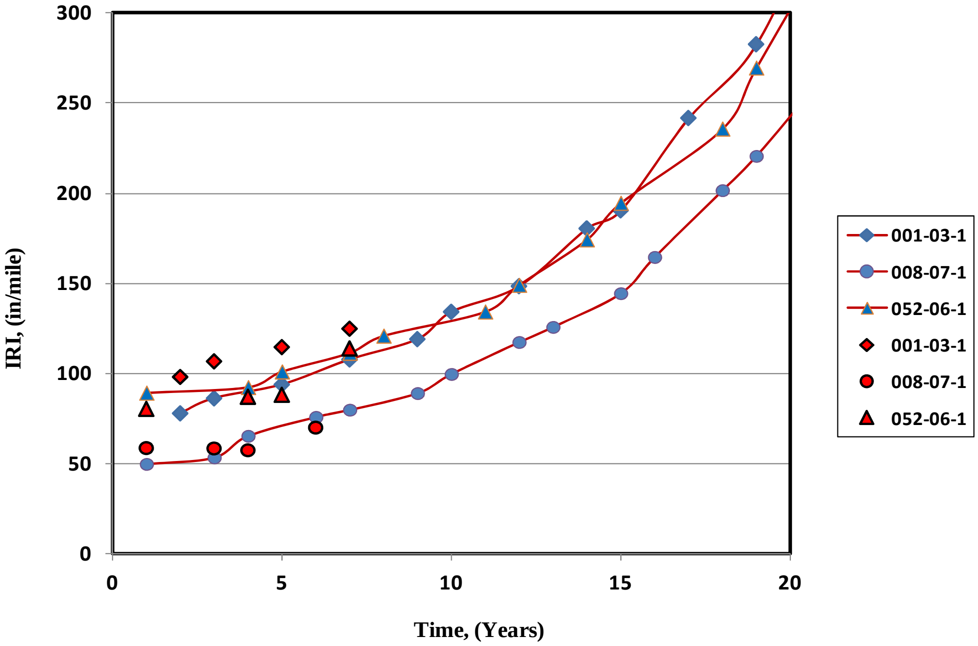


Figure 65

IRI model behavior against measured IRI values for composite pavement

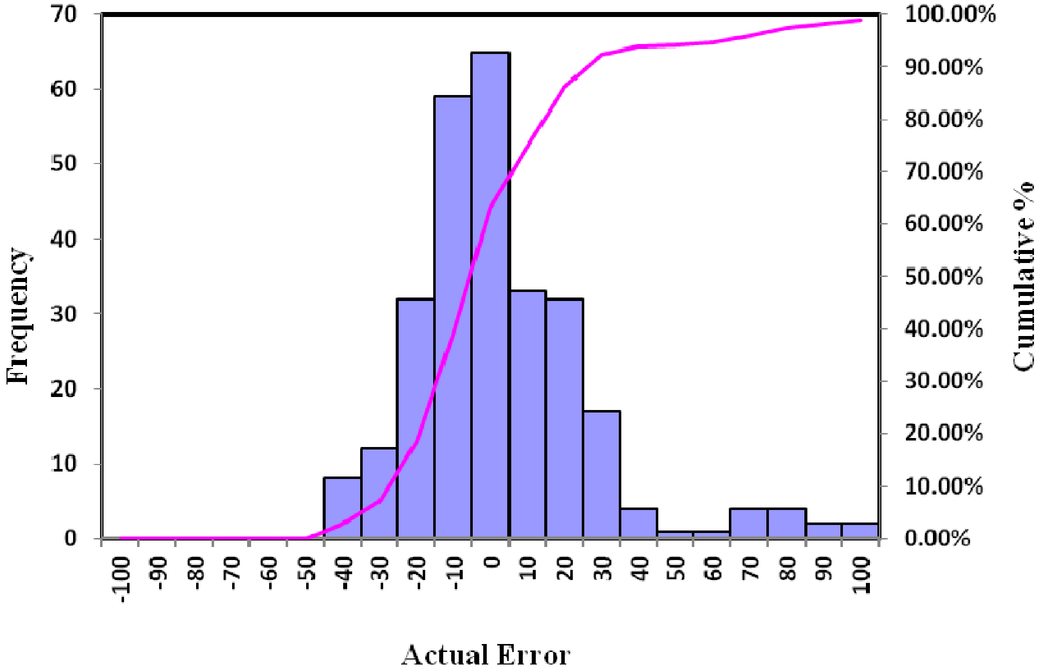


Figure 66
Actual error between measured and predicted values of IRI

Transverse Cracking. In this study, 931.3 km (578.7 miles) of composite pavement were analyzed and regression analyses were conducted on 553.3 km (343.8 miles) of data for transverse cracking based on data availability and project acceptance criterion. The following form of the equation was obtained using the linear regression analysis.

$$\ln\left(\frac{TC+1}{Max-(TC+1)}\right)=a_o+a_1*\ln(CESAL)+a_2*\left(\frac{T_{HMA}}{T_{PCC}}\right)*\left(\frac{1}{Fn}\right)+a_3*CLTI+a_4*CTI \quad (28)$$

Where, TC equals transverse cracking (ft/mile), Max equals 10560 ft/mile, $CESAL$ equals cumulative ESAL, T_{HMA} equals thickness of HMA overlay (in), T_{PCC} equals thickness of PCC layer (in), Fn equals functional classification, $CLTI$ equals cumulative Low Temperature Index (°F-days), CTI equals cumulative Temperature Index (°F-days). The results of the statistical analysis are shown in Table 55.

After conducting the regression, the following equations were obtained to predict the actual transverse and longitudinal cracking.

$$TC = \frac{10560}{1 + \exp^{-\left(\alpha*(-10.134+0.353*Ln(CESAL)-7.302*(T_{HMA}/T_{PCC})*(1/Fn)+6.117*10^{-3}CLTI+2.726*10^{-4}CTI)\right)}} - 1 \quad (29)$$

Here, *TC* equals transverse cracking (ft/lane-mile), α equals 0.7325 for transverse crack is calibration factor obtained by minimizing the RMSE value using the above model.

The predicted versus the measured *ln((TC+1)/(Max-(TC+1))* value for overlay treatment on composite pavement is shown in Figure 67. It can be seen that there is a good agreement between the predicted and measured values, thus indicating that the models were able to predict the transverse cracking reasonably well. Furthermore, all the variables used in the models are statistically significant with p-value ≤0.05. Figure 68 depict the predicted TC for three different projects when plotted against time. Measured TC values were also plotted as scattered points. It can be seen that the model showed reasonable behavior and exhibited compatible results with the measured values. Figure 69 shows actual error distribution of transverse crack and it shows random trend, which is necessary for a good model.

Table 55

Statistics of the regression analysis of TC model for composite pavement of Overlay Treatment

Regression Statistics				
Multiple R			0.64	
R Square			0.41	
Adjusted R Square			0.4	
Standard Error			2.03	
Observations			363	
F-statistics			61.28	
Significance-F			$1.1\text{x}10^{-39}$	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-10.1337	1.1187	-9.2015	0
a_1	0.3534	0.0985	3.5701	0.0004
a_2	-7.3021	1.6063	-4.5245	0
a_3	6.117^{-03}	0.0013	4.7704	0
a_4	2.726^{-04}	0	8.1431	0

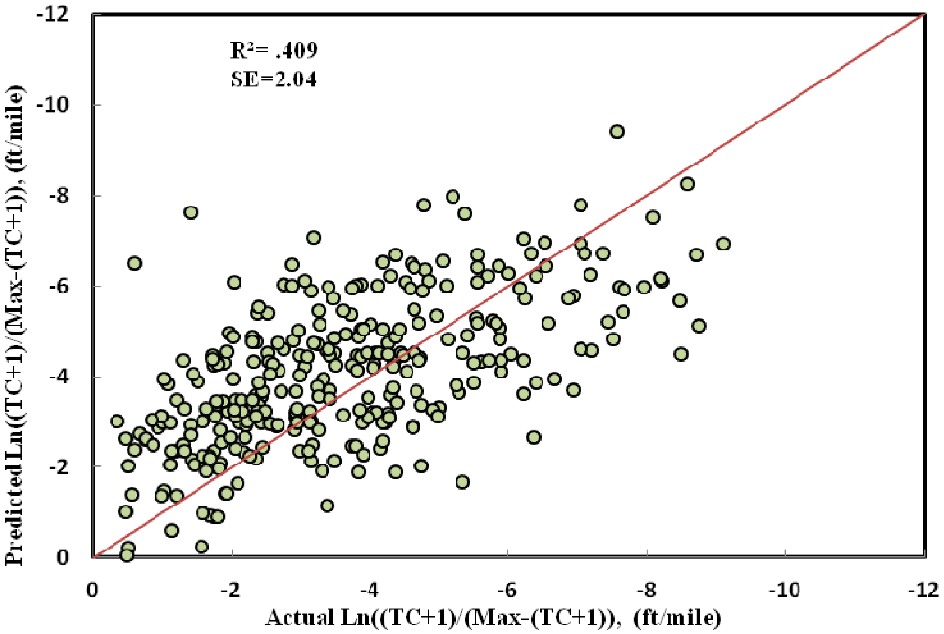


Figure 67

Predicted versus actual Ln((TC+1)/(Max-(TC+1))

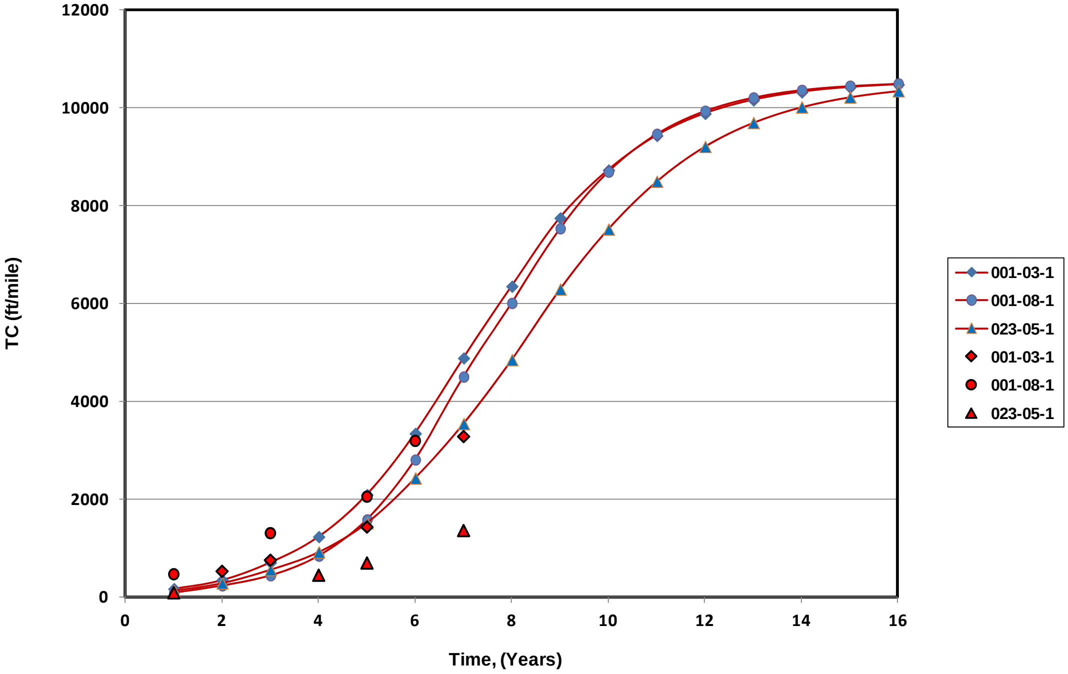


Figure 68

TC model behavior for composite pavement

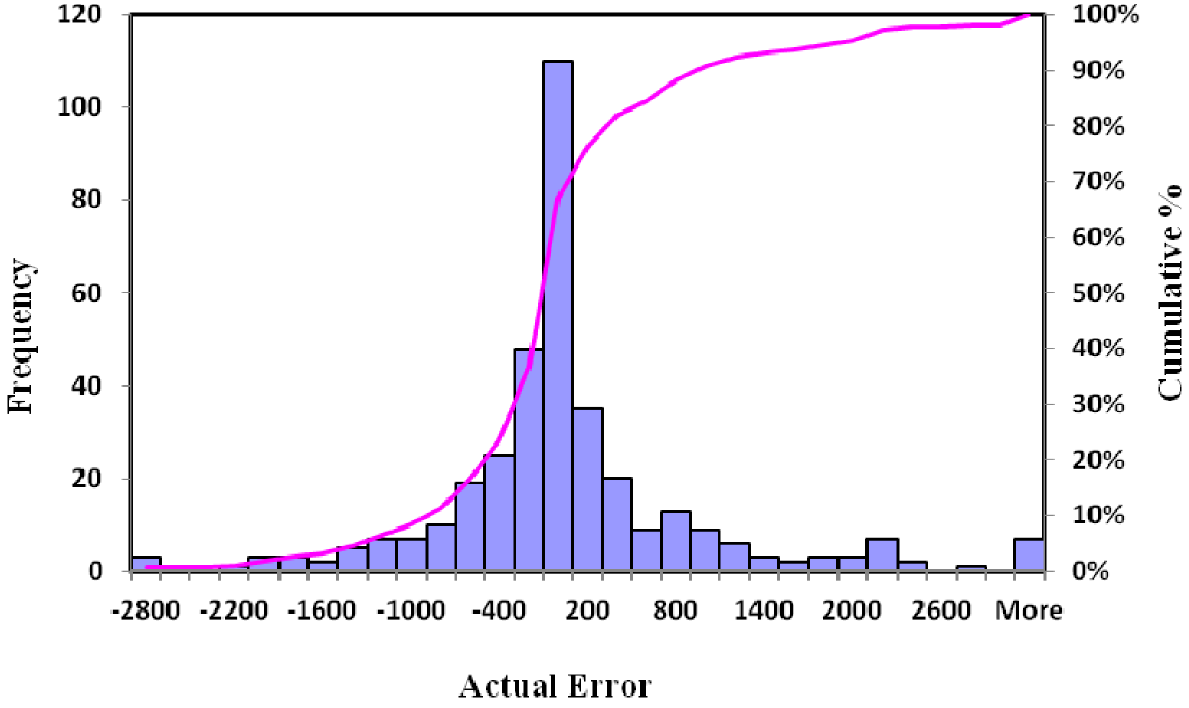


Figure 69
Actual error distribution of transverse crack using regression model

Longitudinal Cracking. In this study, 931.3 km (578.7 miles) of composite pavements were analyzed and regression analyses were conducted on 501.6 km (311.7 miles) of data for longitudinal cracking (based on data availability and project acceptance criterion). The following form of the equation was obtained using the linear regression analysis.

$$\ln\left(\frac{LC+1}{Max-(LC+1)}\right)=a_o+a_1*\ln(CESAL)+a_2*\left(\frac{T_{HMA}}{T_{PCC}}\right)*\left(\frac{1}{Fn}\right)+a_3*CLTI+a_4*CTI \quad (30)$$

Where, LC equals transverse cracking (ft/mile), Max equals 10560 ft/mile, $CESAL$ equals cumulative ESAL, T_{HMA} equals thickness of HMA overlay (in), T_{PCC} equals thickness of PCC layer (in), Fn equals functional classification, $CLTI$ equals cumulative Low Temperature Index (°F-days), and CTI equals cumulative Temperature Index (°F-days). The results of statistical analysis are shown in Table 56.

After conducting the regression, the following equations were obtained to predict the actual transverse and longitudinal cracking.

$$LC = \frac{10560}{1 + \exp^{-\left(\alpha * (-11.614 + .0342 * ln(CESAL) - 9.707 * (T_{HMA} / T_{PCC}) * (1/Fn) + 7.104 * 10^{-3} * CLTI + 3.860 * 10^{-4} * CTI)\right)}} - 1 \quad (31)$$

Here, *LC* equals longitudinal cracking (ft/lane-mile), α equals 0.6526 for longitudinal crack is calibration factor obtained by minimizing the RMSE value using the above models.

The predicted versus the measured *ln((LC+1)/(Max-(LC+1))* values for overlay treatment on composite pavement is shown in Figure 70. It can be seen that there is a good agreement between the predicted and measured values, thus indicating that the models were able to predict the transverse and longitudinal cracking reasonably well. Furthermore, all the variables used in the models are statistically significant with p-value ≤0.05. Figure 71 depicts the predicted LC for three different projects when plotted against time. Figure 72 shows actual error distribution of longitudinal crack and it shows random trend, which is necessary for a good model.

Table 56
Statistics of the regression analysis of LC model for composite pavement

Regression Statistics				
Multiple R			0.70	
R Square			0.49	
Adjusted R Square			0.49	
Standard Error			2.19	
Observations			318	
F-statistics			75.74	
Significance-F			7.60E-45	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-11.6142	0.6521	-19.7924	0.0000
a_1	0.3422	0.0043	4.0796	0.0001
a_2	-9.7079	0.0033	2.5269	0.0134
a_3	7.104E-03	0.0001	7.6683	0.0000
a_4	3.860E-04	0.0001	7.6683	0.0000

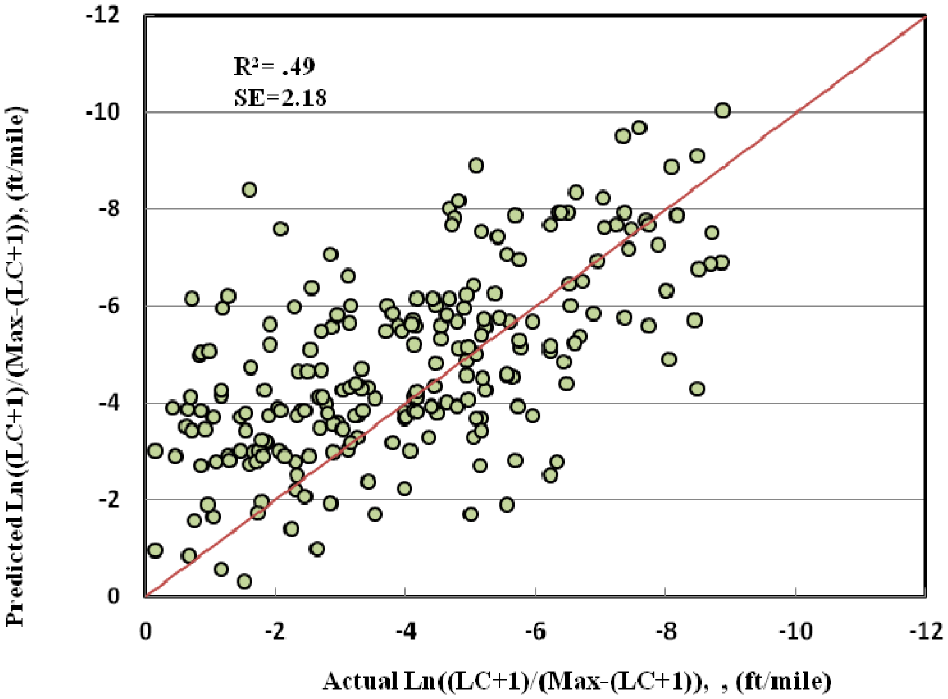


Figure 70
Predicted versus actual Ln((LC+1)/(Max-(LC+1))for composite pavement

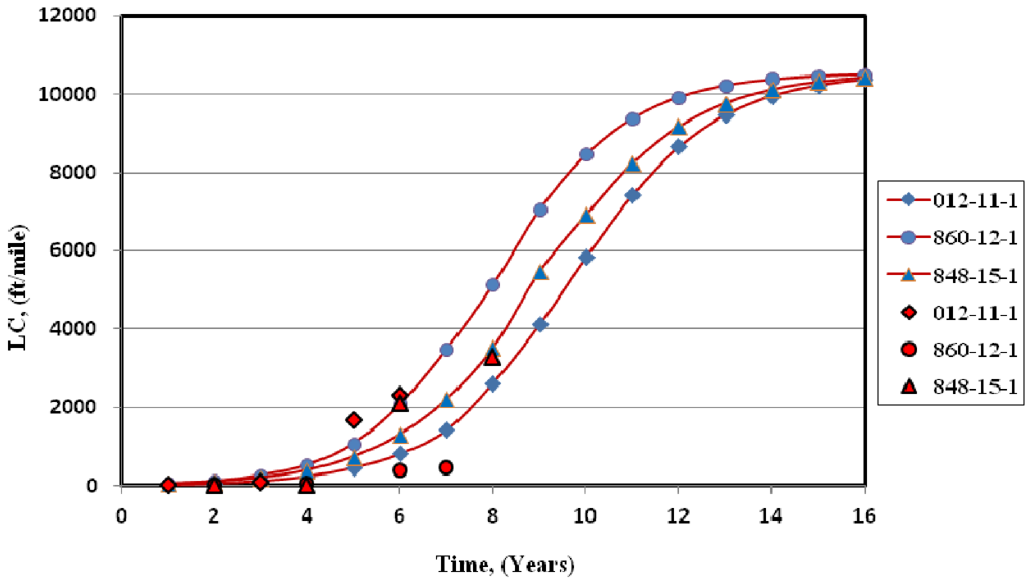


Figure 71
LC model behavior for composite pavement

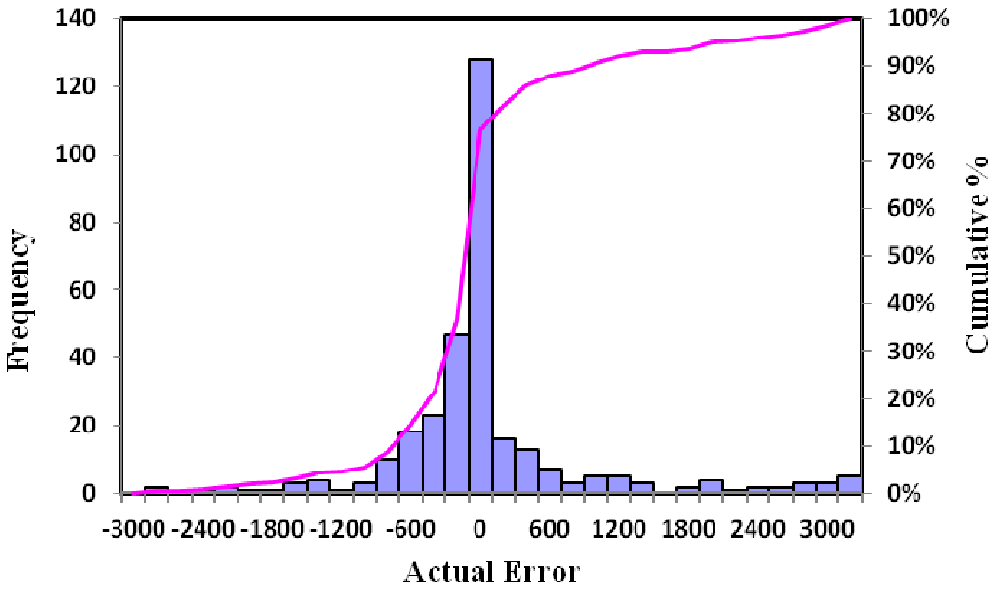


Figure 72
Actual error distribution of longitudinal crack using regression model

Fatigue Cracking. For fatigue cracking, 931.3 km (578.7 miles) of composite pavement were analyzed. However, based on the data availability and project acceptance criterion, about 183.6 km (114.1 miles) of data was utilized for regression analyses. The regression analysis yielded the following form of the equation:

$$\ln\left(\frac{FC+1}{Max-(FC+1)}\right)=a_0+a_1*\frac{\ln(CESAL)}{(T_{HMA}/T_{PCC})}*Fn+a_2*CLTI+a_3*CTI \tag{32}$$

Where, FC equals fatigue cracking (ft^2/lane-mile), Max equals 31680 ft^2 / mile, $CESAL$ equals cumulative ESAL, T_{HMA} equals thickness of HMA overlay (in), T_{PCC} equals thickness of PCC layer (in), Fn equals functional classification, CTI equals cumulative Temperature Index (°F-days), $CLTI$ equals cumulative Low Temperature Index (°F-days). The results of the statistical analysis are shown in Table 57.

After the regression, the final form of the actual fatigue cracking was found to be:

$$FC = \frac{31680}{1+\exp^{-\left(\alpha*(-12.95+0.0176*\frac{\ln(CESAL)}{(T_{HMA}/T_{PCC})}*Fn+8.385*10^{-3}*CLTI+4.879*10^{-4}*CTI)\right)}} - 1 \qquad (33)$$

Here, *FC* equals fatigue cracking (ft²/lane-mile) and α equals *0*.7719 is a calibration factor obtained by minimizing the root-mean-square error (RMSE) value using the above fatigue cracking model.

Figure 73 shows the predicted versus the measured *ln((FC+1)/(Max-(FC+1))* values for overlay treatment on composite pavement. The figure shows that, with the exception of a few data points, there is a good agreement between the predicted and measured values, thus indicating that the model is able to predict the fatigue cracking reasonably well. Also, from the data in Table 57, it is clear that all the variables are statistically significant with p-value ≤0.05. Figure 75 shows actual error distribution of fatigue crack and it shows random trend which is necessary for a good model.

Table 57
Statistics of the regression analysis of FC model for composite pavement

Regression Statistics				
Multiple R			0.76	
R Square			0.57	
Adjusted R Square			0.55	
Standard Error			2.03	
Observations			86	
F-statistics			36.44	
Significance-F			4.56×10^{-15}	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-12.9501	0.6521	-19.7924	0.0000
a_1	0.0176	0.0043	4.0796	0.0001
a_2	8.385×10^{-3}	0.0033	2.5269	0.0134
a_3	4.879×10^{-4}	0.0001	7.6683	0.0000

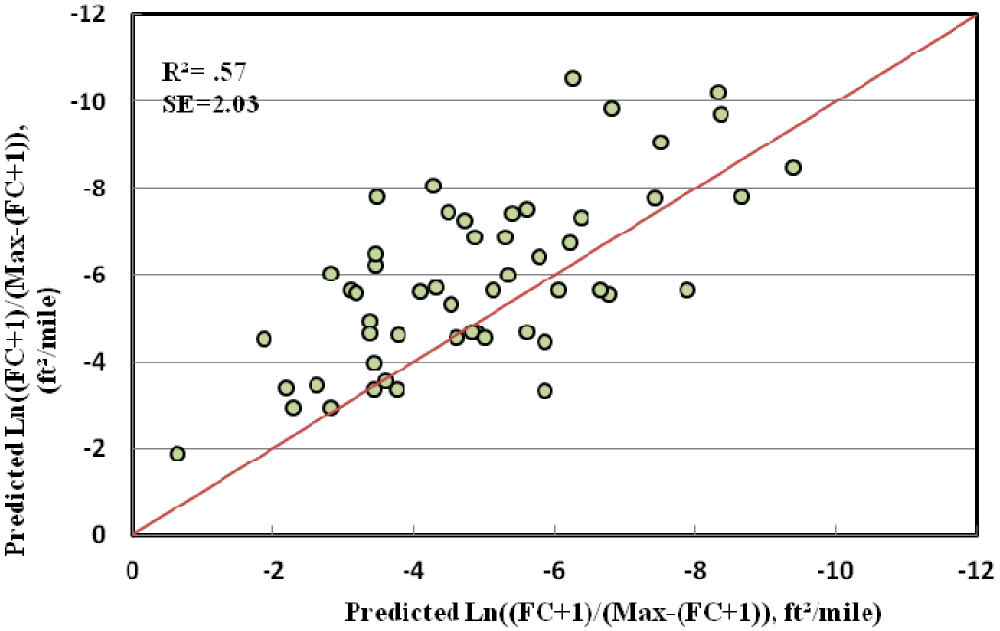


Figure 73
Predicted versus actual Ln((FC+1)/(Max-(FC+1))for composite pavement

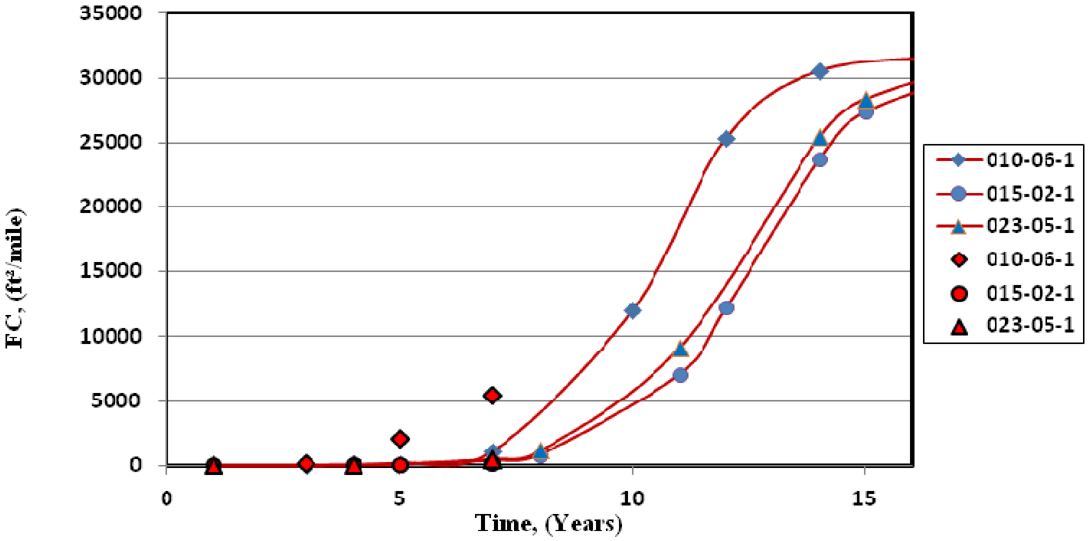


Figure 74
FC model behavior for composite pavement

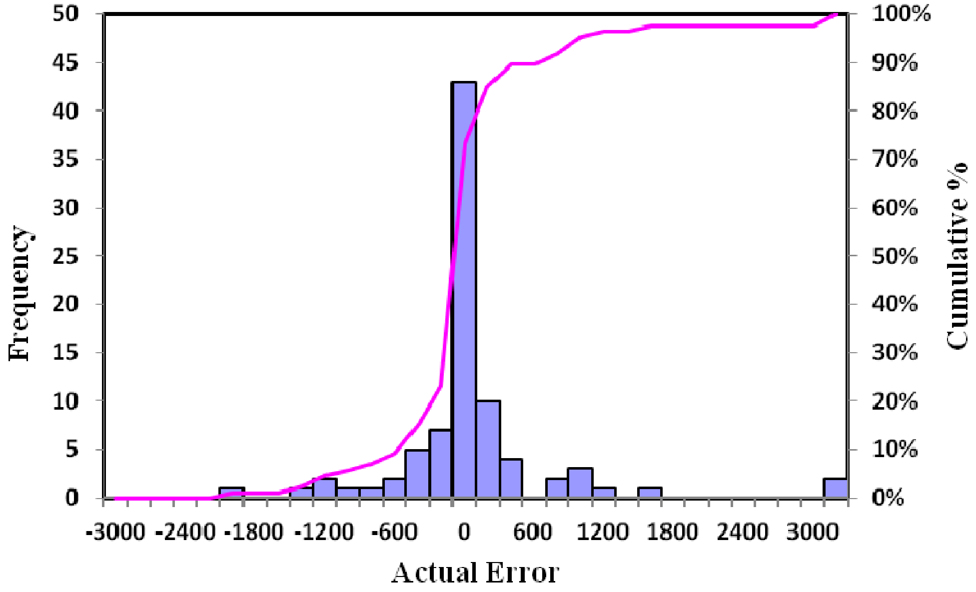


Figure 75
Actual error distribution of FC using regression model

Rut. For developing the rutting model, 931.3 km (578.7 miles) of composite pavements were analyzed. However, based on the data availability and project acceptance criterion, about 541.7 km (336.6 miles) of data was utilized for regression analyses.

$$\ln(Rut) = a_o + a_1 * \ln(CESAL) + a_2 * \frac{Fn}{(T_{HMA} / T_{PCC})} * \ln(t) \tag{34}$$

Where, Rut equals average rut depth per lane (in), $CESAL$ equals cumulative ESAL, T_{HMA} equals thickness of HMA overlay, T_{PCC} equals thickness of PCC layer, Fn equals functional classification, and t equals age of treatment (year).

After the regression, the final form of the rutting was found to be:

$$Rut = \exp\left(\alpha * (-6.146 + 0.264 * \ln(CESAL) + 0.053 * \frac{Fn}{(T_{HMA} / T_{PCC})} * \ln(t))\right) \tag{35}$$

Here, *Rut* equals average rut depth per lane (in), and α equals *1.0164* is a calibration factor obtained by minimizing the RMSE value using the above model.

Figure 76 shows the predicted versus the measured Ln(Rut) values for overlay treatment on composite pavement. Figure 77 shows rut model behavior when plotted against actual values. Figure 78 shows actual error distribution of rut and it shows random trend which is necessary for a good model. Also, from the data in Figure 73, it is clear that all the variables are statistically significant with p-value ≤ 0.05.

Table 58

Statistics of the regression analysis of Rut model for composite pavement

Regression Statistics				
Multiple R			0.89	
R Square			0.79	
Adjusted R Square			0.79	
Standard Error			0.62	
Observations			364	
F-statistics			693.26	
Significance-F			2.35×10^{-124}	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-6.147	0.302	-20.301	0.00
a_1	0.264	0.025	10.505	0.00
a_2	0.0536	0.003	15.246	0.00

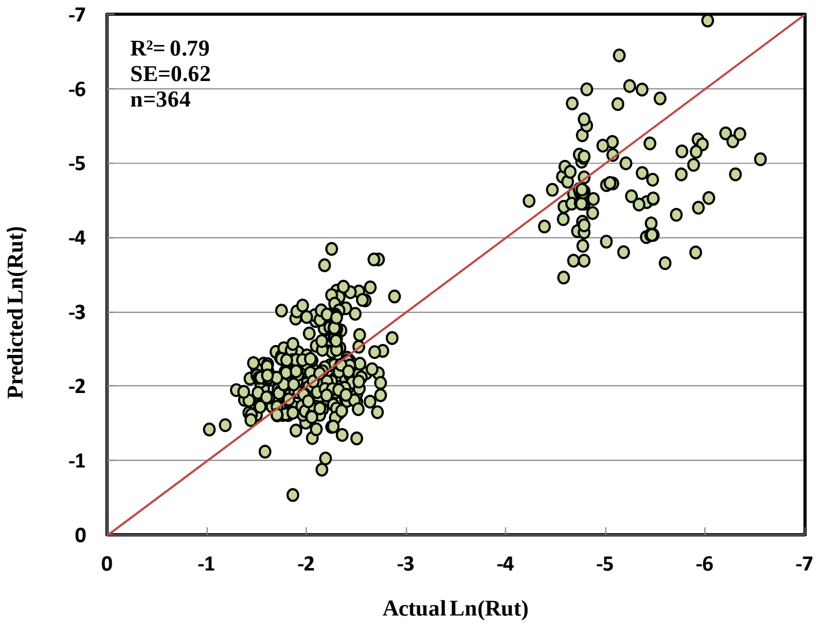


Figure 76

Predicted versus actual Ln(Rut) for composite pavement

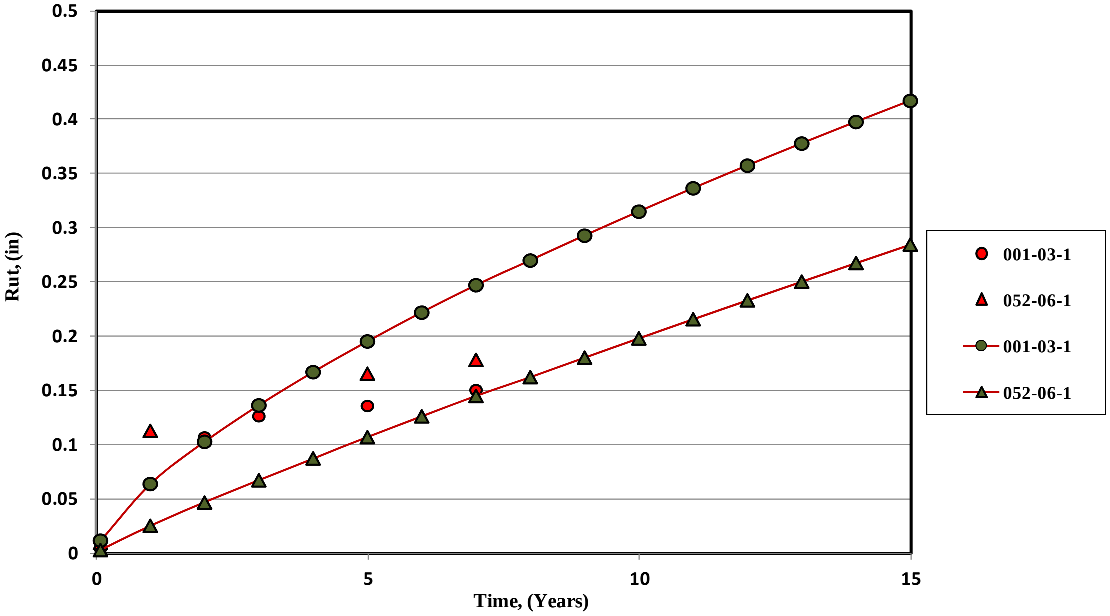


Figure 77

Rut model behavior against measured Rut values for composite pavement

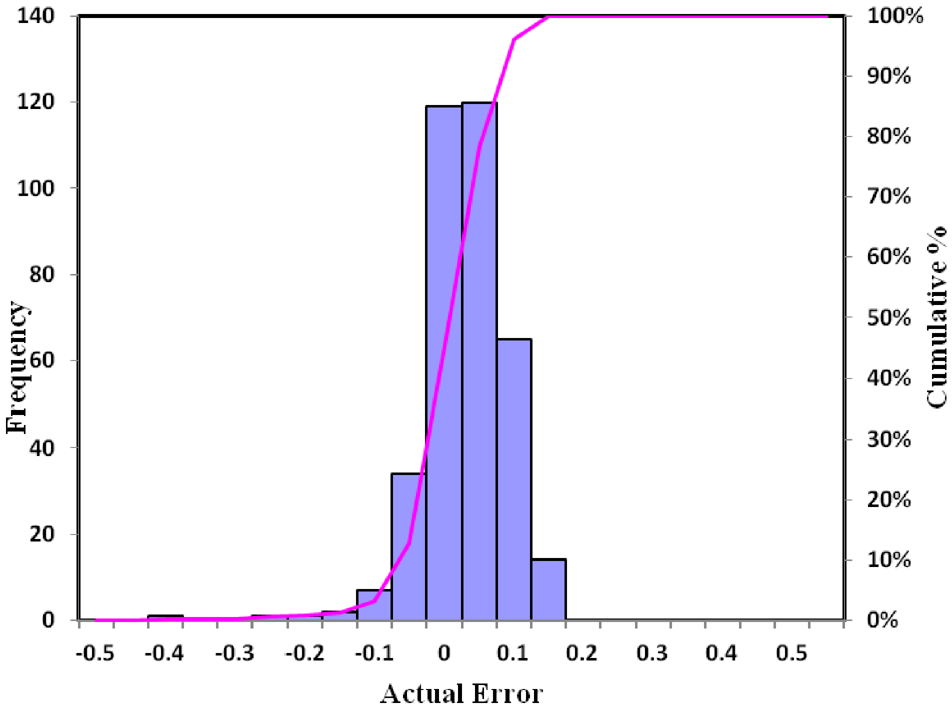


Figure 78
Actual error distribution of rut using regression model

Flexible Pavement with Overlay Treatment

International Roughness Index (IRI) Model. Based on the methodology adopted for pavement treatment project selection, about 817.7 miles of flexible pavements were initially identified where HMA overlay treatment was applied. However, some of the projects lacked necessary data and after further scrutinizing, 170 projects were selected, comprising of 726.2 miles of flexible pavement. Regression analysis was conducted and following model was developed.

$$\ln(IRI) = a_0 + a_1 * \frac{1}{Fn} + a_2 * \frac{\ln(CESAL)}{T_H} + a_3 * TI + a_4 * CPI * t + \Delta \qquad (36)$$

Where, IRI unit equals in/mile, IRI_p equals IRI value before treatment, CESAL equals cumulative ESAL, T_H equals thickness of HMA overlay, Fn equals functional classification, TI equals temperature index (Degree Fahrenheit-days), t equals age of treatment (year), CPI equals cumulative precipitation index (in-days) and $\Delta = -0.5098 + 0.2448 \ln(IRI_{pp})$. Where, IRI_{pp} equals predicted value of IRI of the previous year. After the regression, the final form of the IRI was found to be:

$$IRI = \exp\left(\alpha * (3.331 - 0.2798 * \frac{1}{Fn} + 0.04755 * \frac{\ln(CESAL)}{T_H} + 0.0001478 * TI + 2.33E - 7 * CPI * t + \Delta\right) \quad (37)$$

Here, α equals *1.003* is a calibration factor obtained by minimizing the RMSE value using the above model.

The results of statistical analysis are shown in Table 59. Figure 79 shows the predicted versus the measured ln(IRI) values for overlay treatment on flexible pavement. It shows that, with an exception of a few data points, there is a good agreement between the predicted and measured IRI values, thus indicating that the model was able to predict the IRI reasonably well. Similarly Figure 80 illustrates the model behavior for a few selected projects. From Figure 81, it can be seen that the error distribution of IRI is normal which an indication of good applicable model. Also, as evidenced in Table 59, it is clear that all the variables are statistically significant at p-value ≤ 0.05.

Table 59

Statistics of the regression analysis of IRI model for flexible pavement

Regression Statistics				
Multiple R			0.68	
R Square			0.47	
Adjusted R Square			0.46	
Standard Error			0.16	
Observations			623	
F-statistics			108.95	
Significance-F			2.17×10^{-82}	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	3.331	0.07268	45.83	8.1×10^{-201}
a_1	-0.2798	0.05705	-4.90	1.2×10^{-6}
a_2	0.04755	0.005652	8.41	2.79×10^{-16}
a_3	0.0001478	3.564×10^{-5}	4.15	3.83×10^{-5}
a_4	2.33E-07	3.736×10^{-8}	6.25	7.71×10^{-10}

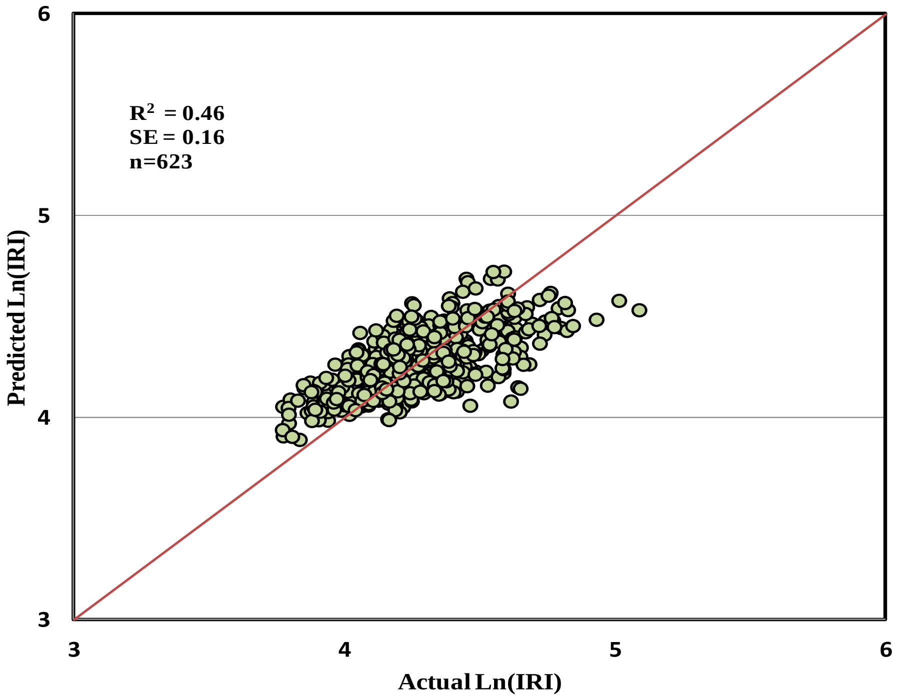


Figure 79

Predicted versus actual ln(IRI) for flexible pavement

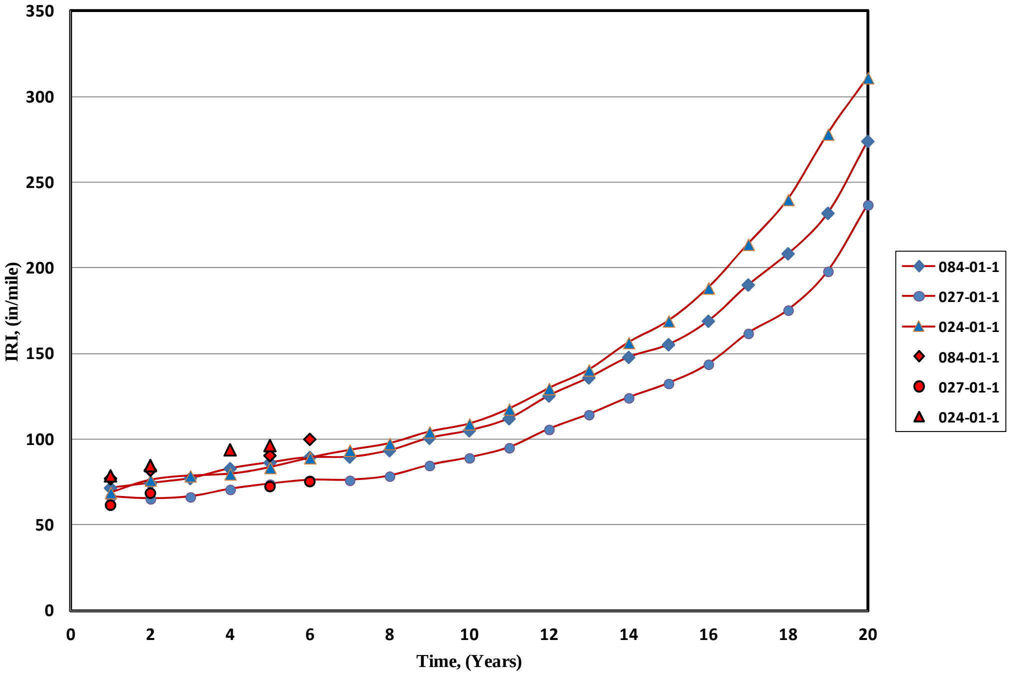


Figure 80

IRI Model behavior against measured IRI values for flexible pavement

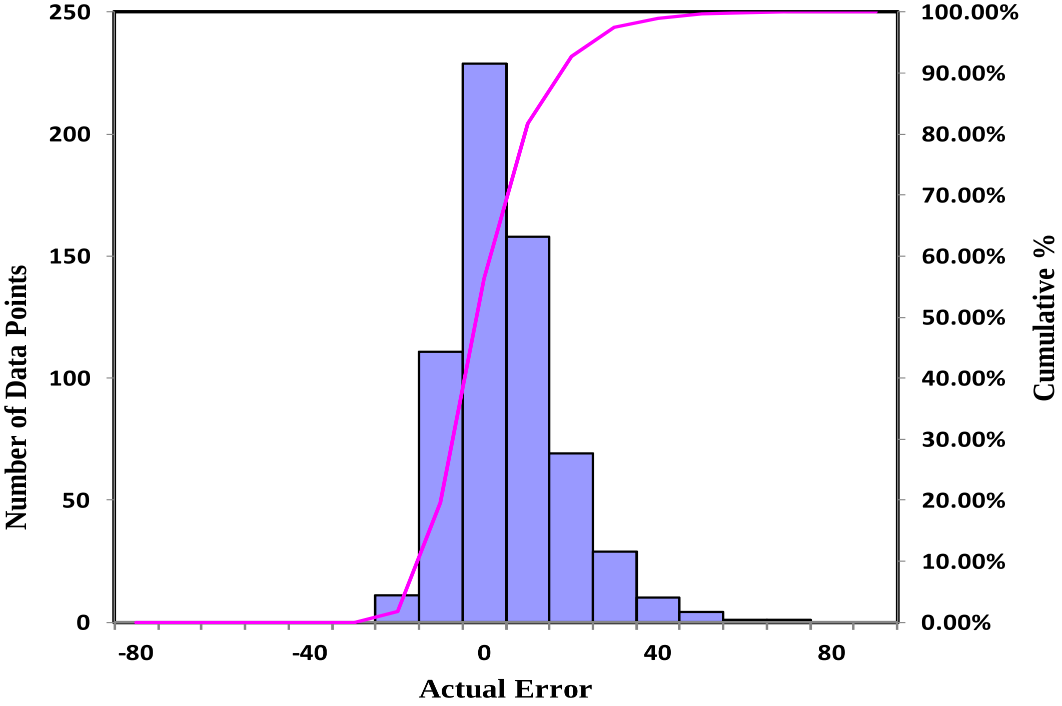


Figure 81

Actual error between measured and predicted values of IRI

Transverse Cracking. In this study, 817.7 miles of flexible pavements were analyzed and regression analyses were conducted on 797.1 miles of data for transverse cracking based on data availability and project acceptance criterion. The following form of the equation was obtained using the linear regression analysis.

$$\ln\left(\frac{TC+1}{Max-(TC+1)}\right)=a_o+a_1*\left(\frac{1}{Fn}\right)+a_2*\frac{\ln(CESAL)}{T_H}+a_3*t \qquad (38)$$

Where, TC equals transverse cracking (ft/mile), Max equals 10560 ft/mile, $CESAL$ equals cumulative ESAL, T_H equals thickness of HMA overlay (in), Fn equals functional classification, $CLTI$ equals cumulative Low Temperature Index (°F-days), CTI equals cumulative Temperature Index (°F-days). The results of statistical analysis are shown in Table 60.

After conducted the regression, the following equations were obtained to predict the actual transverse cracking.

$$TC = \frac{10560}{1 + \exp^{-\left(-7.619 - 3.524 * \left(\frac{1}{Fn}\right) + 0.3375 * \frac{\ln(CESAL)}{T_H} + 0.6947 * t\right)}} - 1 \tag{39}$$

The predicted versus the measured *ln((TC+1)/(Max-(TC+1))* value for overlay treatment on flexible pavement is shown in Figure 82. It can be seen that there is a good agreement between the predicted and measured values, thus indicating that the models were able to predict the transverse cracking reasonably well. Furthermore, all the variables used in the models are statistically significant with p-value ≤0.05. Figure 83 depict the predicted TC for three different projects when plotted against time. Measured TC values were also plotted as scattered points. It can be seen that the model showed reasonable behavior and exhibited compatible results with the measured values. Figure 84 shows actual error distribution of transverse crack and it shows random trend which is necessary for a good model.

Table 60

Statistics of the regression analysis of TC model for flexible pavement of Overlay Treatment

Regression Statistics				
Multiple R			0.63	
R Square			0.40	
Adjusted R Square			0.40	
Standard Error			2.02	
Observations			735	
F-statistics			162.95	
Significance-F			7.13×10^{-81}	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-7.619	0.2384	-31.95	6.93×10^{-141}
a_1	-3.524	0.5251	-6.71	3.90×10^{-11}
a_2	0.3375	0.06065	5.57	3.68×10^{-08}
a_3	0.6947	0.03696	18.80	1.35×10^{-64}

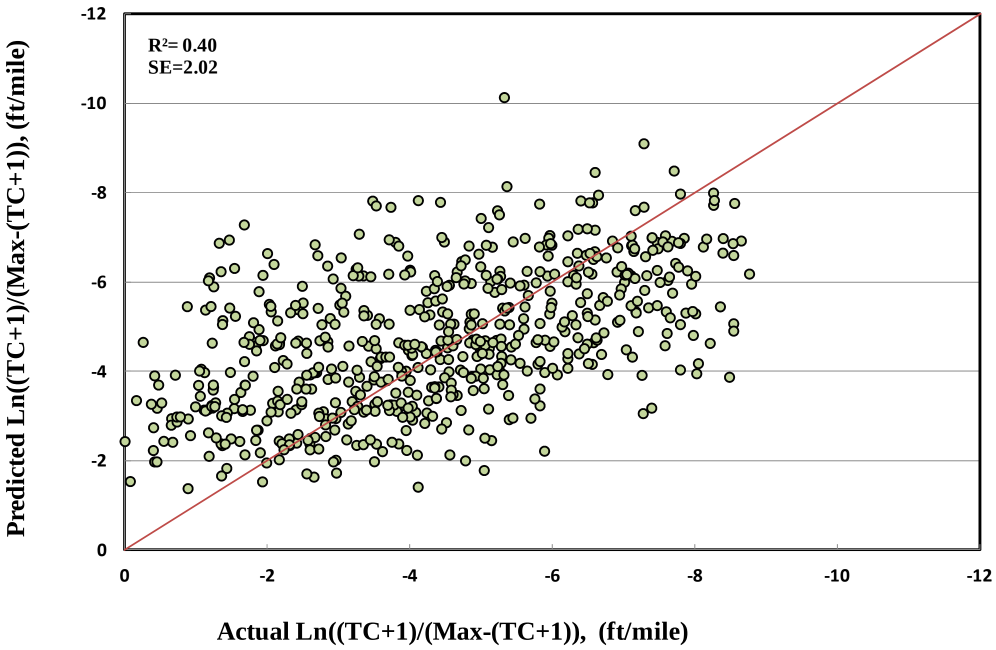


Figure 82

Predicted versus actual Ln((TC+1)/(Max-(TC+1))

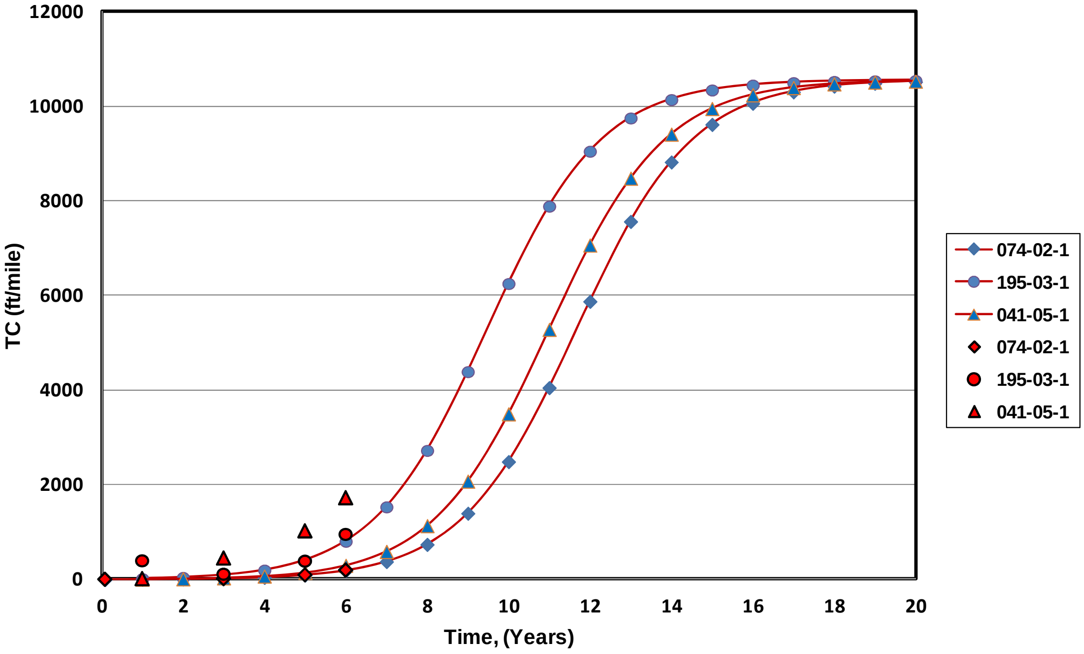


Figure 83

TC model behavior for flexible pavement

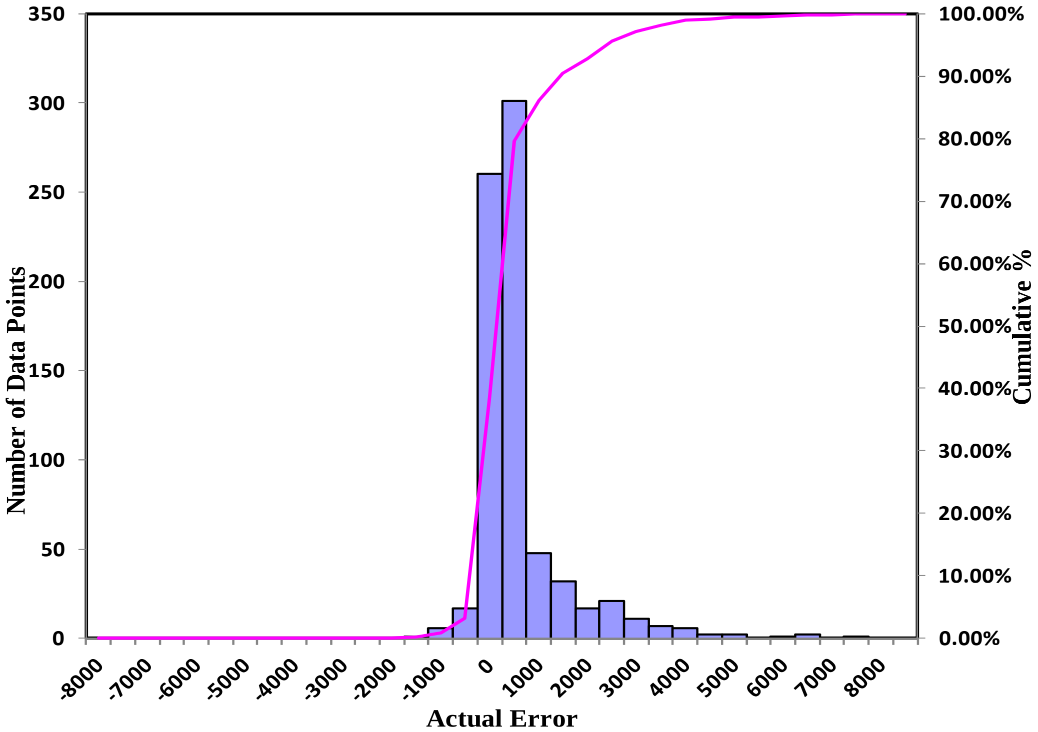


Figure 84

Actual error distribution of transverse crack using regression model

Longitudinal Cracking. In this study, 817.7 miles of flexible pavements were analyzed and regression analyses were conducted on 790 miles of data for longitudinal cracking (based on data availability and project acceptance criterion). The following form of the equation was obtained using the linear regression analysis.

$$\ln\left(\frac{LC+1}{Max-(LC+1)}\right) = a_o + a_1 * \frac{\ln(CESAL)}{T_H} + a_2 * \left(\frac{1}{Fn}\right) + a_3 * CLTI + a_4 * CTI \qquad (40)$$

Where, LC equals transverse cracking (ft/mile), Max equals 10560 ft/mile, $CESAL$ equals cumulative ESAL, T_H equals thickness of HMA overlay (in), Fn equals functional classification, $CLTI$ equals cumulative Low Temperature Index (°F-days), CTI equals cumulative Temperature Index (°F-days). The results of statistical analysis are shown in Table 61.

After conducting the regression, the following equations were obtained to predict the actual longitudinal cracking.

$$LC = \frac{10560}{1 + \exp^{-\left(-7.893 + 0.1240 * \frac{\ln(CESAL)}{TH} - 3.373 * \left(\frac{1}{Fn}\right) + 0.005009 * CLTI + 0.0003336 * CTI\right)}} - 1 \qquad (41)$$

The predicted versus the measured *ln((LC+1)/(Max-(LC+1))* values for overlay treatment on flexible pavement is shown in Figure 85. It can be seen that there is a good agreement between the predicted and measured values, thus indicating that the models were able to predict the transverse and longitudinal cracking reasonably well. Furthermore, all the variables used in the models are statistically significant with p-value ≤0.05. Figure 86 depicts the predicted LC for three different projects when plotted against time. Figure 87 shows actual error distribution of longitudinal crack and it shows random trend, which is necessary for a good model.

Table 61

Statistics of the regression analysis of LC model for flexible pavement

Regression Statistics				
Multiple R			0.65	
R Square			0.43	
Adjusted R Square			0.42	
Standard Error			1.94	
Observations			713	
F-statistics			131.24	
Significance-F			$7.87\text{x}10^{-84}$	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-7.893	0.2333	-33.83	$4.89\text{x}10^{-150}$
a_1	0.1240	0.06122	2.03	$4.32\text{x}10^{-2}$
a_2	-3.373	0.5326	-6.33	$4.26\text{x}10^{-10}$
a_3	0.005009	0.0009406	5.32	$1.36\text{x}10^{-7}$
a_4	0.0003336	0.00002023	16.49	$6.38\text{x}10^{-52}$

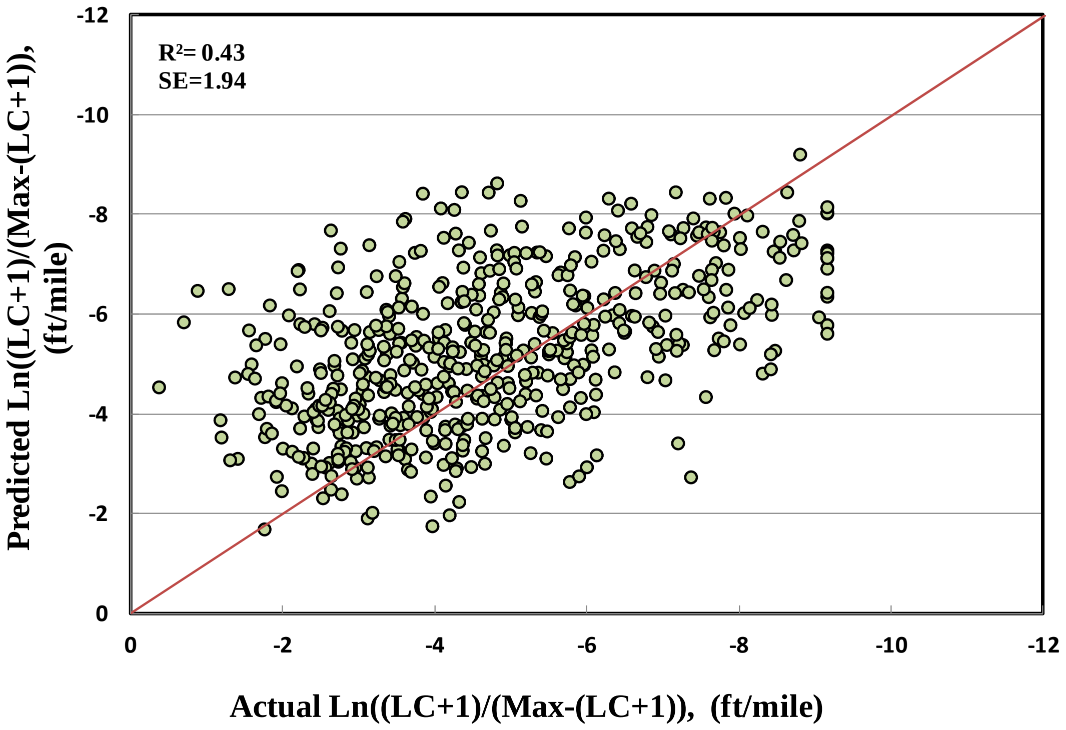


Figure 85
Predicted versus actual Ln((LC+1)/(Max-(LC+1))for flexible pavement

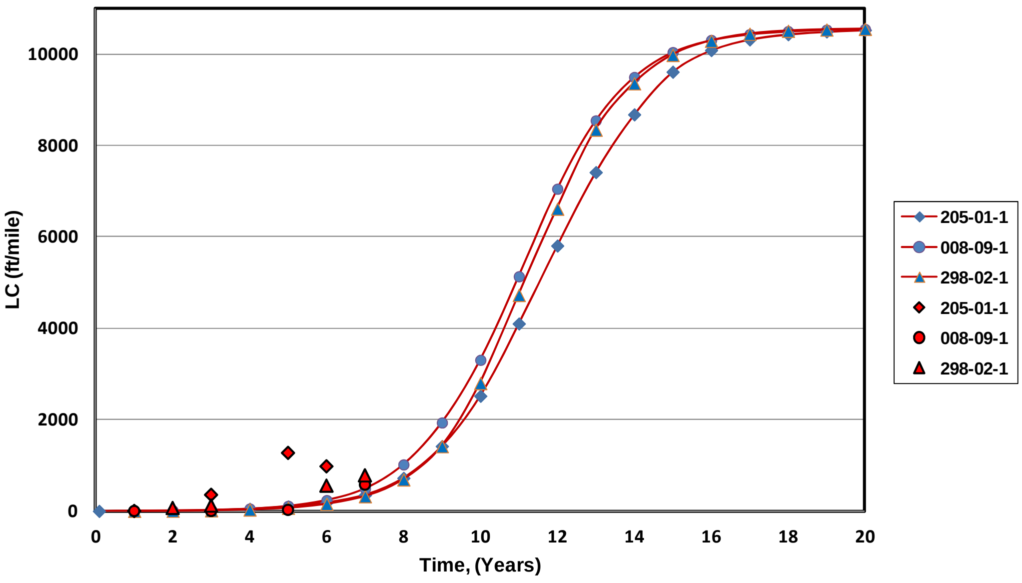


Figure 86
LC model behavior for flexible pavement

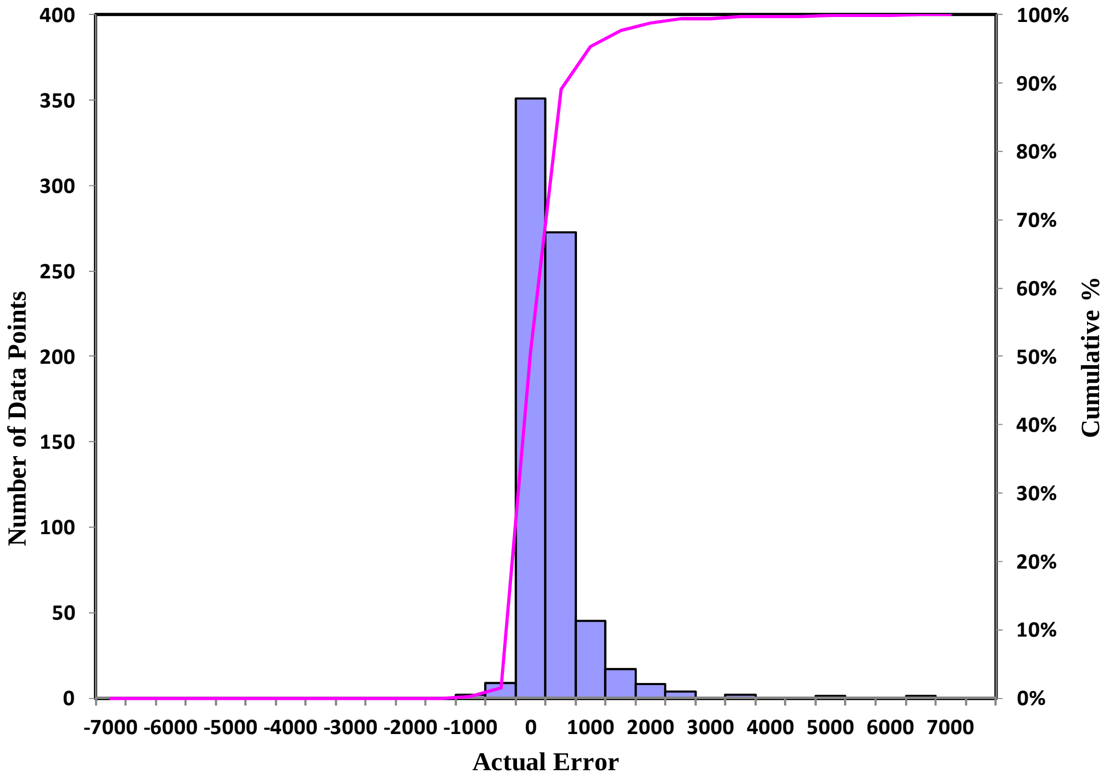


Figure 87

Actual error distribution of longitudinal crack using regression model

Fatigue Cracking. For fatigue cracking, 817.7 miles of flexible pavements were analyzed. However based on the data availability and project acceptance criterion about 716.6 miles of data was utilized for regression analyses. The regression analysis yielded the following form of the equation:

$$\ln\left(\frac{FC+1}{Max-(FC+1)}\right)=a_o+a_1*\frac{\ln(CESAL)}{T_H}+a_2*\left(\frac{1}{Fn}\right)+a_3*CLTI+a_4*CTI \qquad (42)$$

Where, FC equals fatigue cracking (ft²/lane-mile), Max equals 31680 ft^2/mile, $CESAL$ equals cumulative ESAL, T_H equals thickness of HMA overlay (in), PCC equals thickness of PCC layer (in), Fn equals functional classification, CTI equals cumulative Temperature Index (°F-days), $CLTI$ equals cumulative Low Temperature Index (°F-days). The results of statistical analysis are shown in Table 62.

After the regression, the final form of the actual fatigue cracking was found to be:

$$FC = \frac{31680}{1 + \exp^{-\left(-7.57 + 0.3545 * \frac{\ln(CESAL)}{TH} - 6.451 * \left(\frac{1}{Fn}\right) + 0.004581 * CLTI + 0.0003626 * CTI\right)}} - 1 \qquad (43)$$

Figure 88 shows the predicted versus the measured *ln((FC+1)/(Max-(FC+1))* values for overlay treatment on flexible pavement. The figure depicts that, with an exception of a few data points, there is a good agreement between the predicted and measured values, thus indicating that the model is able to predict the fatigue cracking reasonably well. Also, from the data in Table 62, it is clear that all the variables are statistically significant with p-value ≤0.05. Figure 89 depicts the predicted FC for three different projects when plotted against time. Figure 90 shows actual error distribution of fatigue crack and it shows random trend which is necessary for a good model.

Table 62

Statistics of the regression analysis of FC model for flexible pavement

Regression Statistics				
Multiple R			0.66	
R Square			0.44	
Adjusted R Square			0.44	
Standard Error			2.20	
Observations			640	
F-statistics			124.43	
Significance-F			2.21E-78	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-7.570	0.2896	-26.14	8.30×10^{-103}
a_1	0.3545	0.07830	4.53	7.12×10^{-6}
a_2	-6.451	0.6910	-9.34	1.66×10^{-19}
a_3	0.004581	0.001145	4.00	7.02×10^{-5}
a_4	0.0003626	0.00002438	14.87	3.99×10^{-43}

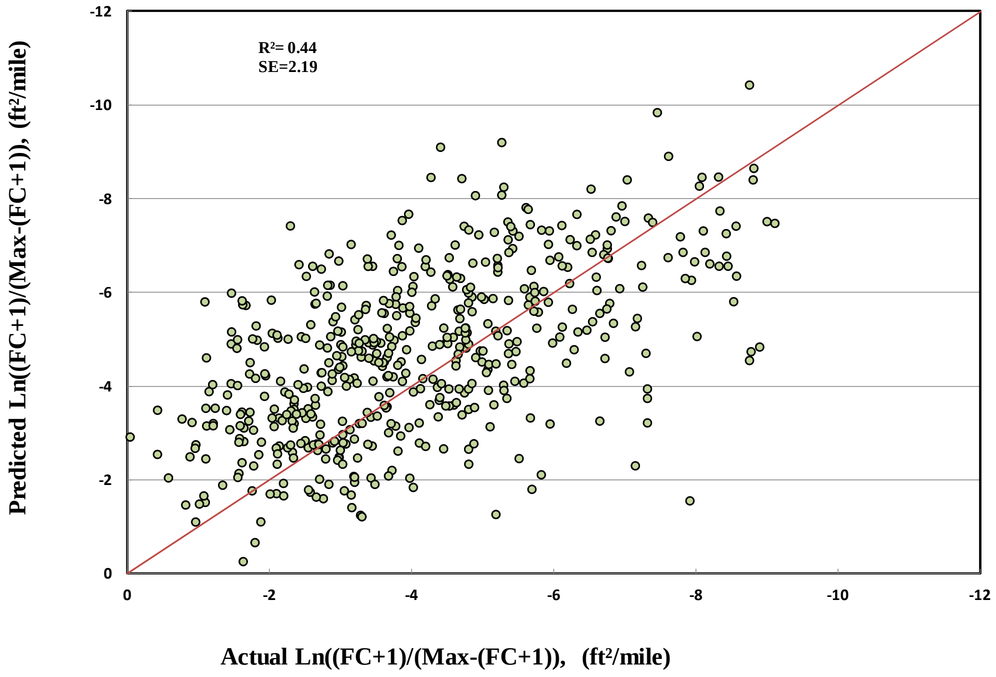


Figure 88

Predicted versus actual Ln((FC+1)/(Max-(FC+1))for flexible pavement

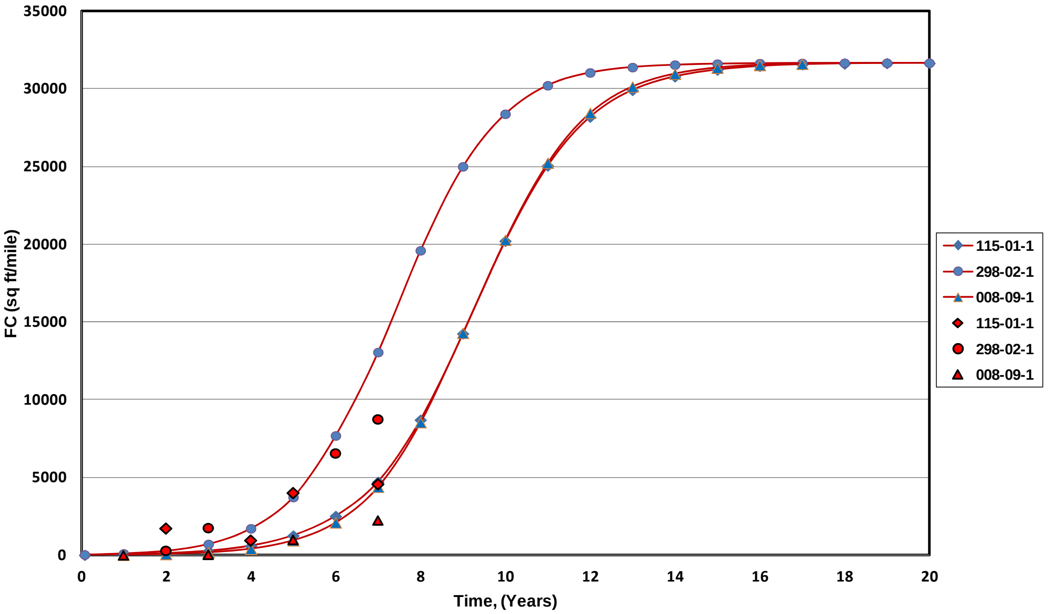


Figure 89

LC model behavior for flexible pavement

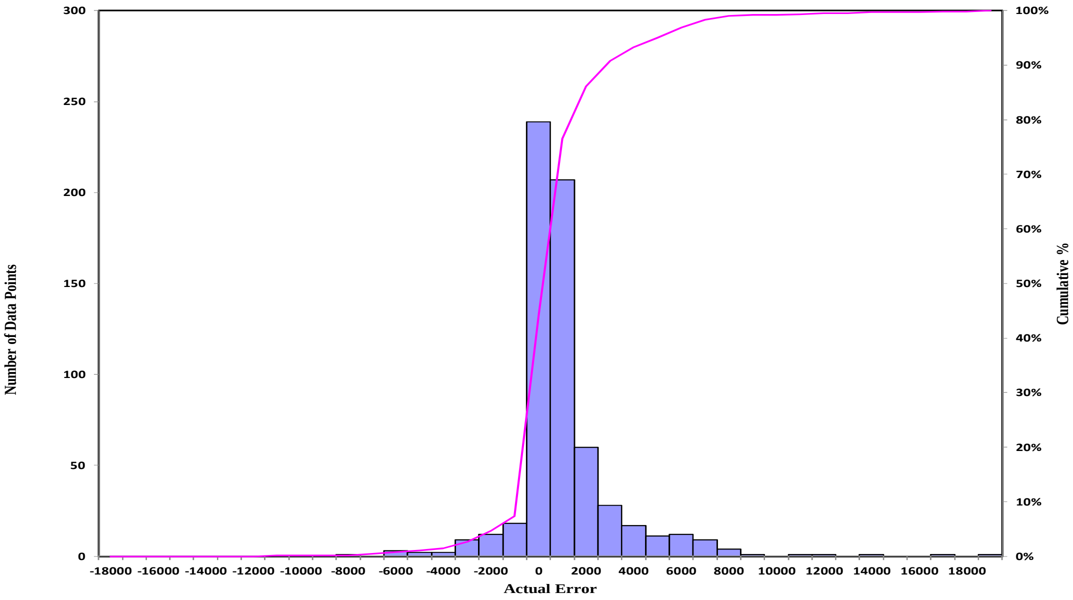


Figure 90
Actual error distribution of rut using regression model

Rut Prediction. For developing rutting model, 817.7 miles of flexible pavements were analyzed. However based on the data availability and project acceptance criterion about 777.4 miles of data was utilized for regression analyses. Prediction models for rutting were based on functional classification. For functional classification: 1, 2, and 3.

$$\ln(Rut) = a_0 + a_1 * \frac{Fn}{T_{HMA}} + a_2 * \ln(t) + a_3 * \ln(CESAL) \tag{44}$$

Where, *Rut* equals average rut depth per lane (in), *CESAL* equals cumulative ESAL, T_{HMA} equals thickness of HMA overlay, T_{PCC} equals thickness of PCC layer, *Fn* equals functional classification, *t* equals age of treatment (year). The results of statistical analysis are shown in Table 63.

After the regression, the final form of the rutting was found to be:

$$Rut = \exp\left(-3.851 + 0.4114 * \frac{Fn}{T_{HMA}} + 0.7259 * \ln(t) + 0.0409 * \ln(CESAL)\right) \tag{45}$$

For functional classification: 4, 5, and 9.

$$\ln(Rut) = a_0 + a_1 * \frac{Fn}{T_{HMA}} + a_2 * \ln(t) + a_3 * \ln(CESAL) \qquad (46)$$

The results of statistical analysis are shown in Table 64. After the regression, the final form of the rutting was found to be:

$$Rut = \exp\left(-4.135 + 0.1331 * \frac{Fn}{T_{HMA}} + 0.6017 * \ln(t) + 0.07061 * \ln(CESAL) \right) \qquad (47)$$

Figure 91 shows the predicted versus the measured ln(Rut) values for overlay treatment on flexible pavement for all functional classifications by combining both equations. Figure 92 shows rut model behavior when plotted against actual values. Figure 93 shows actual error distribution of rut and it shows random trend which is necessary for a good model. Also, from the data in Table 63 and Table 64, it is clear that all the variables are statistically significant with p-value ≤0.05.

Table 63

Statistics of the regression analysis of Rut model for flexible pavement for functional classification 1, 2, and 3

Regression Statistics				
Multiple R			0.91	
R Square			0.83	
Adjusted R Square			0.82	
Standard Error			0.60	
Observations			177	
F-statistics			273.73	
Significance-F			1.96×10^{-65}	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-3.851	0.4604	-8.36	1.95×10^{-14}
a_1	0.4114	0.1334	3.08	2.37×10^{-3}
a_2	0.7259	0.04487	16.18	1.91×10^{-36}
a_3	0.04090	0.03541	1.16	0.0250

Table 64

Statistics of the regression analysis of Rut model for flexible pavement for functional classification 4, 5, and 9

Regression Statistics	
Multiple R	0.88
R Square	0.78
Adjusted R Square	0.78
Standard Error	0.60
Observations	612
F-statistics	729.74
Significance-F	$5.53\text{x}10^{-201}$

Coefficients	Value	Standard Error	t-stats	p-values
a_o	-4.135	0.1862	-22.20	$1.96\text{x}10^{-80}$
a_1	0.1331	0.03635	3.66	$2.72\text{x}10^{-4}$
a_2	0.6017	0.02079	28.94	$2.04\text{x}10^{-116}$
a_3	0.07061	0.01558	4.53	$7.05\text{x}10^{-6}$

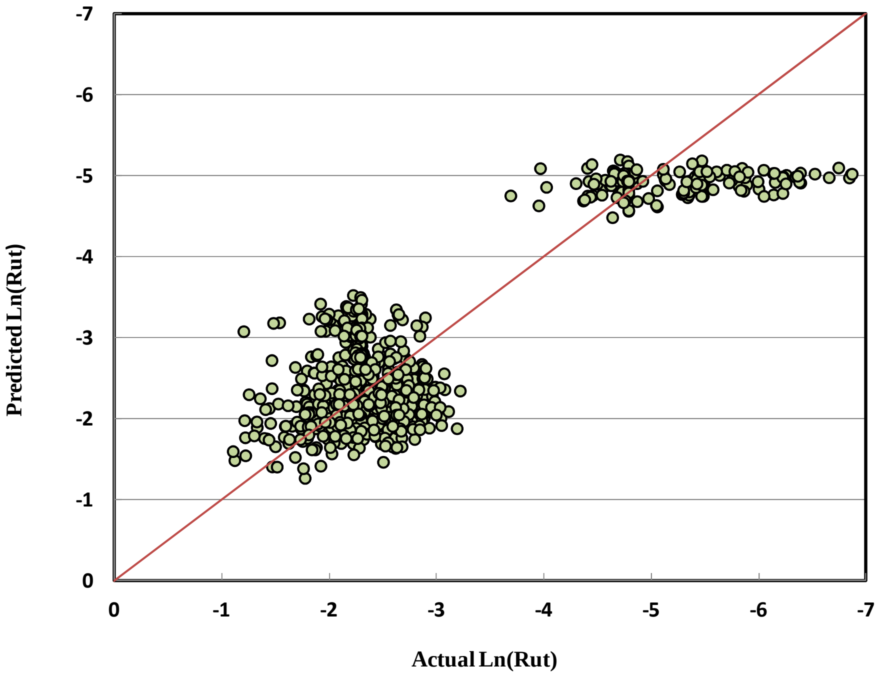


Figure 91

Predicted versus actual Ln(Rut) for flexible pavement for all functional classification

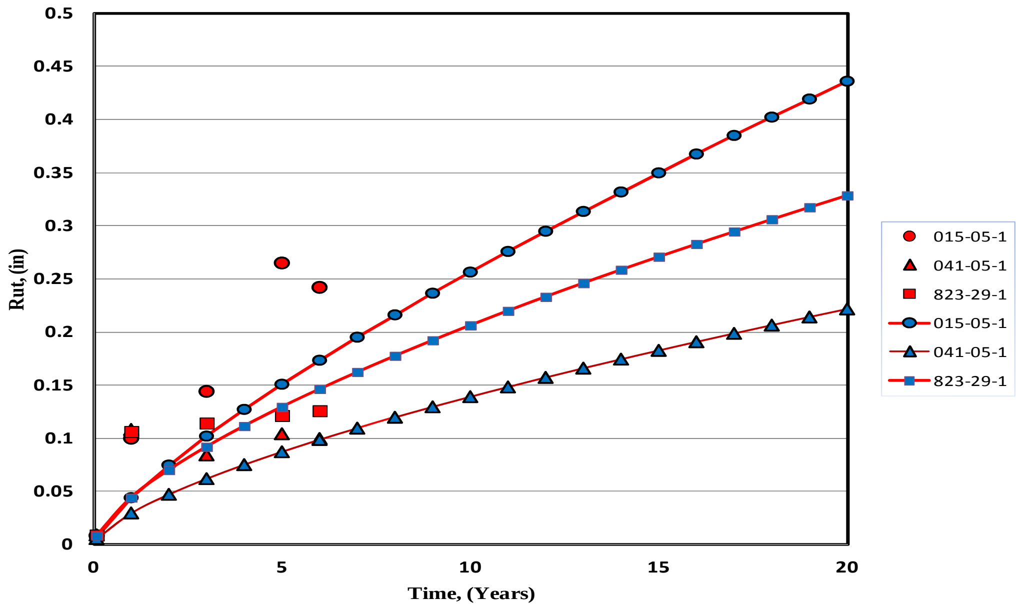


Figure 92

Rut model behavior and measured rut values for flexible pavement

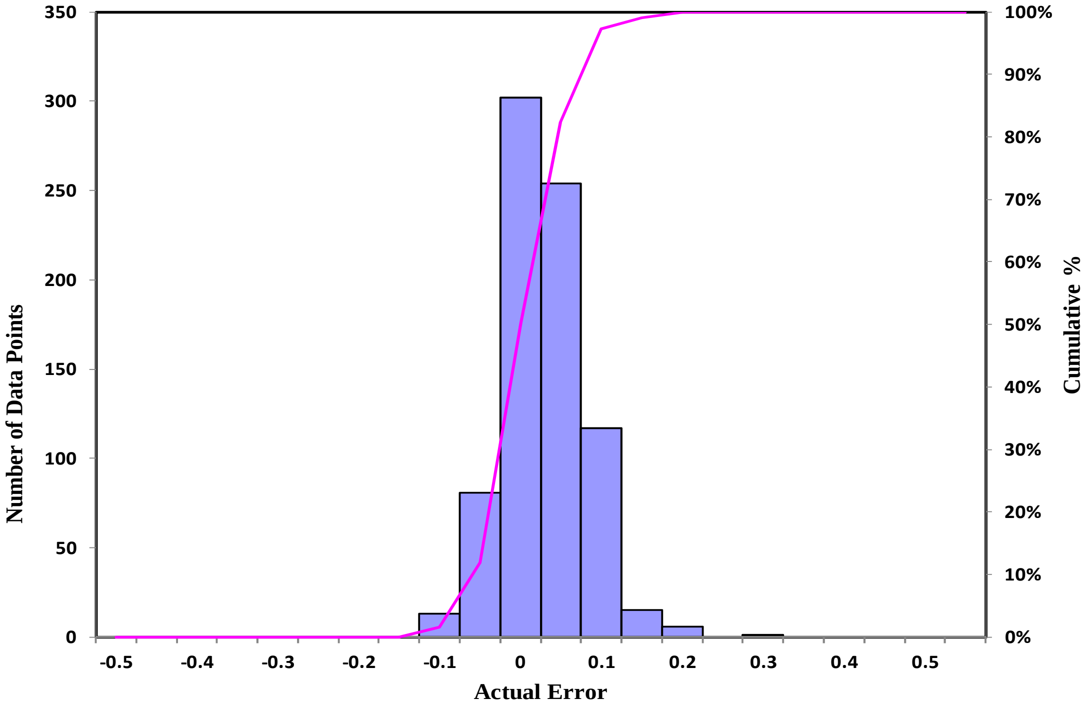


Figure 93

Actual error distribution of rut using regression model

Composite Pavement with Chipseal Treatment

Similar to the above mentioned approach for composite pavement and flexible pavement, all other distress models for other pavements and treatments have been completed. Only the equations will be presented below; the statistical table and figures relating the validity of the model will be provided in Appendix D.

International Roughness Index (IRI) Model.

$$IRI = \exp\left(1.002 * (2.331 + 0.000621 * \frac{\ln(CESAL)}{Ap} + 0.00406 * \ln(IRI_p) + 1.714 * 10^{-6} * CTI * t)\right) \quad (48)$$

$R^2 =$ 0.43 Standard Error = 0.17 n = 54 F-Statistics = 12.59

Transverse Cracking.

$$TC = \frac{10560}{1 + \exp^{-\left((0.648)(-6.467+0.4465*ln(CESAL)-5.936*(Ap/Fn)+2.479*10^{-4}*CTI\right)}} - 1 \quad (49)$$

$R^2 =$ 0.33 Standard Error = 2.22 n = 58 F-Statistics = 9.06

Longitudinal Cracking.

$$LC = \frac{10560}{1 + \exp^{-\left((0.6122)*(-7.661+0.0437*ln(CESAL)*(Fn/Ap)+4.85*10^{-4}*CTI\right)}} - 1 \quad (50)$$

$R^2 =$ 0.44 Standard Error = 2.26 n = 53 F-Statistics = 19.84

Fatigue Cracking.

$$FC = \frac{31680}{1 + \exp^{-\left((1.1004)*(-10.777+0.1886*ln(CESAL)*(Fn/Ap)\right)}} - 1 \qquad (51)$$

$R^2 =$ 0.75 Standard Error = 1.66 n = 9 F-Statistics = 20.86

Rut Prediction Model.

$$Rut = \exp\left(1.007*(-5.602+0.335*\ln(CESAL)+0.073*\frac{Fn}{Ap}*\ln(t))\right) \qquad (52)$$

$R^2 =$ 0.77 Standard Error = 0.67 n = 71 F-Statistics = 113.6

Composite Pavement with Microsurfacing Treatment

International Roughness Index.

$$IRI = \exp\left(4.24+3.108*10^{-3}*\ln(CESAL)*t\right) \qquad (53)$$

$R^2 =$ 0.96 Standard Error = 0.02 n = 4 F-Statistics = 61.62

Transverse Cracking.

$$TC = \frac{10560}{1 + \exp^{-\left(-6.411+0.0712*ln(CESAL)*t\right)}} - 1 \qquad (54)$$

$R^2 =$ 0.89 Standard Error = 0.71 n = 363 F-Statistics = 39.73

Longitudinal Cracking.

$$LC = \frac{10560}{1 + \exp^{-\left(-8.223 + 0.0931 * Ln(CESAL) * t\right)}} - 1 \tag{55}$$

$R^2 =$ 0.73 Standard Error = 1.63 n = 8 F-Statistics = 16.25

Fatigue Cracking.

$$FC = \frac{31680}{1 + \exp^{-\left(-8.407 + 0.0923 * ln(CESAL) * t\right)}} - 1 \tag{56}$$

$R^2 =$ 1 Standard Error = 0 n = 2

Rut.

$$Rut = \exp\left(0.4195 * \ln(t) + 1.338 * \ln(Rut_p)\right) \tag{57}$$

$R^2 =$ 0.99 Standard Error = 0.05 n = 5 F-Statistics = 4264.3

JCP Pavement with Chipseal Treatment

International Roughness Index.

$$IRI = \exp(0.5278 + 0.845 * \ln(IRIp) + 6.105 * 10^{-3} * \ln(CESAL) * Fn + 0.033 * t) \tag{58}$$

$R^2 =$ 0.99 Standard Error = 0.05 n = 11 F-Statistics = 227.59

Transverse Cracking.

$$TC = \frac{3960}{1 + \exp^{-\left(-4.213 + 0.0554 * Ln(CESAL)*t\right)}} - 1 \qquad (59)$$

$R^2 =$ 0.51 Standard Error = 1.5 n = 11 F-Statistics = 9.25

Longitudinal Cracking.

$$LC = \frac{10560}{1 + \exp^{-\left(-11.163 + 0.549 * Ln(CESAL) + 0.477 * t\right)}} - 1 \qquad (60)$$

$R^2 =$ 0.60 Standard Error = 1.51 n = 12 F-Statistics = 6.703

Fatigue Cracking.

$$FC = \frac{31680}{1 + \exp^{-\left(-8.00 + 0.145 * Ln(CESAL)*t\right)}} - 1 \qquad (61)$$

$R^2 =$ 0.91 Standard Error = 1.11 n = 4 F-Statistics = 20.24

Rut.

$$Rut = \exp\left(-1.957 + 0.2344 * \ln(t)\right) \qquad (62)$$

$R^2 =$ 1.00 Standard Error = 0.01 n = 3 F-Statistics = 2538.8

JCP Pavement with Microsurfacing Treatment

International Roughness Index.

$$IRI = \exp(3.995 + 5.473 * 10^{-3} * \ln(CESAL) * t) \qquad (63)$$

$R^2 =$ 0.80 Standard Error = 0.09 n = 7 F-Statistics = 20.12

Transverse Cracking.

$$TC = \frac{3960}{1 + \exp^{-\left(-5.28 + 0.0455 * Ln(CESAL)*t\right)}} - 1 \tag{64}$$

$R^2 =$ 0.95 Standard Error = 0.33 n = 7 F-Statistics = 102.25

Longitudinal Cracking.

$$LC = \frac{10560}{1 + \exp^{-\left(-10.717 + 0.0765 * Ln(CESAL)*t\right)}} - 1 \tag{65}$$

$R^2 =$ 0.68 Standard Error = 1.57 n = 8 F-Statistics = 12.94

Fatigue Cracking.

$$FC = \frac{31680}{1 + \exp^{-\left(-11.078 + 0.102 * Ln(CESAL)*t\right)}} - 1 \tag{66}$$

$R^2 =$ 0.92 Standard Error = 1.57 n = 3 F-Statistics = 11.16

Rut.

$$Rut = \exp\left(-2.0818 + 0.1845 * \ln(t)\right) \tag{67}$$

$R^2 =$ 0.80 Standard Error = 0.09 n = 7 F-Statistics = 20.12

Flexible Pavement with Chipseal Treatment:

International Roughness Index.

$$IRI = 1.0593 + 0.7949 * \ln(IRIp) + 0.0002931 * \ln(CESAL) * FnAp + 0.000001862 * CTI * t \tag{68}$$

$R^2 =$ 0.86 Standard Error = 0.12 n = 519 F-Statistics = 1073.9

Transverse Cracking.

$$TC = \frac{10560}{1 + \exp^{-\left(-8.836 + 0.1390 * \ln(CESAL) + 0.0002208 * CTI + 0.5514 * \ln(Crackp + 1) - 3.709 * \frac{Ap}{Fn}\right)}} - 1 \qquad (69)$$

$R^2 =$ 0.35 Standard Error = 1.67 n = 531 F-Statistics = 70.57

Longitudinal Cracking.

$$LC = \frac{10560}{1 + \exp^{-\left(-8.372 + 0.2543 * \left(\frac{\ln(CESAL)}{Ap.Fn}\right) + 0.3468 * \ln(Crackp + 1) + 0.0002568 * CTI\right)}} - 1 \qquad (70)$$

$R^2 =$ 0.33 Standard Error = 1.55 n = 530 F-Statistics = 86.96

Fatigue Cracking.

$$FC = \frac{31680}{1 + \exp^{-\left(-6.295 + 0.3750 * \left(\frac{\ln(CESAL)}{Ap.Fn}\right) + 0.0002643 * CTI\right)}} - 1 \qquad (71)$$

$R^2 =$ 0.2 Standard Error = 2.1 n = 456 F-Statistics = 57.42

Rut.

$$\ln(Rut) = -0.9902 + 0.02204 * \frac{\ln(CESAL) * \ln(t)}{Fn} + 0.4628 * \ln(Rutp) + 0.06319 * Ap \qquad (72)$$

$R^2 =$ 0.29 Standard Error = 0.3 n = 439 F-Statistics = 59.45

Flexible Pavement with Microsurfacing Treatment

International Roughness Index.

$$\ln(IRI) = 0.9028 + 0.7074 * \ln(IRIp) + 0.2499 * Ap + 0.0000004617 * \ln(CESAL) * Fn * t + 0.0000004617 * CPI * t \qquad (73)$$

$R^2 =$ 0.88 Standard Error = 0.17 n = 26 F-Statistics = 55.35

Transverse Cracking.

$$TC = \frac{10560}{1 + \exp^{-\left(-10.86 + 0.04584 * \ln(CESAL) * t + 0.7637 * \ln(Crackp + 1) + 3.0311 * \frac{Ap}{Fn}\right)}} - 1 \qquad (74)$$

$R^2 =$ 0.55 Standard Error = 2.04 n = 34 F-Statistics = 12.38

Longitudinal Cracking.

$$LC = \frac{10560}{1 + \exp^{-\left(-8.372 + 0.2543 * \left(\frac{\ln(CESAL)}{Ap.Fn}\right) + 0.3468 * \ln(Crackp + 1) + 0.0002568 * CTI\right)}} - 1 \qquad (75)$$

$R^2 =$ 0.59 Standard Error = 1.77 n = 34 F-Statistics = 14.62

Fatigue Cracking.

$$FC = \frac{31680}{1 + \exp^{-\left(-8.839 + 1.384 * \frac{\ln(CESAL)}{Ap.Fn} + 0.03989 * CLTI\right)}} - 1 \qquad (76)$$

$R^2 =$ 0.55 Standard Error = 1.92 n = 24 F-Statistics = 12.81

Rut.

$$Rut = \exp\left(-1.7954 + 0.3205 * \ln(IRIp) + 0.01257 * \ln(CESAL) * Ap * \ln(t) + 0.03273 * Fn\right) \qquad (77)$$

$R^2 =$ 0.55 Standard Error = 0.25 n = 28 F-Statistics = 9.65

Flexible Pavement with Replacement

International Roughness Index.

$$IRI = \exp\left(4.9063 + 0.01145 * \frac{\ln(\mathrm{CESAL}) * t}{T_H} - 0.02843 * T_B - \frac{0.8824}{Fn}\right) \qquad (78)$$

$R^2 =$ 0.60 Standard Error = 0.18 n = 57 F-Statistics = 26.99

Where, T_B equals Non-Asphalt Thickness of Base ; T_H equals Thickness of Asphalt Layer(Including Asphalt thickness of Base)

Transverse Cracking.

$$TC = \frac{10560}{1 + \exp^{-\left(-10.04 + 0.00001836 * \ln(\mathrm{CESAL}) * \mathrm{CTI} + 2.665 * \frac{Fn * T_H}{(T_H + T_B)}\right)}} - 1 \qquad (79)$$

$R^2 =$ 0.53 Standard Error = 2.14 n = 57 F-Statistics = 30.05

Longitudinal Cracking.

$$LC = \frac{10560}{1 + \exp^{-\left(-9.347 + 0.00001419 * \ln(\mathrm{CESAL}) * \mathrm{CTI} + 2.037 * \frac{Fn * T_H}{(T_H + T_B)}\right)}} - 1 \qquad (80)$$

$R^2 =$ 0.40 Standard Error = 2.10 n = 50 F-Statistics = 15.77

Fatigue Cracking.

$$FC = \frac{31680}{1 + \exp^{-\left(-4.25 + 0.943 * \ln(CESAL) + 0.00003172 * CPI - 0.3644 * T_H - 0.3447 * T_B - \frac{24.17}{Fn} \right)}} - 1 \qquad (81)$$

$R^2 =$ 0.76 Standard Error = 2.00 n = 48 F-Statistics = 26.86

Rut.

$$Rut = \exp\left(-2.565 + 0.06399 * \ln(CESAL) * \ln(t) - 0.07904 * \frac{T_H}{Fn} - 0.05056 * T_B \right) \qquad (82)$$

$R^2 =$ 0.81 Standard Error = 0.66 n = 65 F-Statistics = 84.45

Deduct Points Calibration and Recommendation

Once again and at the outset, the deduct point systems do not define or cause changes in the trigger values for the selection of project boundaries and treatment type. They simply rank the various pavement sections based on the pavement surface conditions and distress. For each pavement condition and distress, two alternatives deduct point systems are presented and discussed. The two alternatives are based on:

1. The existing DOTD deduct point systems.
2. The continuity and consistency of the deduct points relative to the extent and severity of the pavement conditions and distresses.
3. The pavement distress and condition models that are available in the literature especially those embedded in the new AASHTO M-E PDG.

Alligator Cracking

Crack saturation for alligator cracking is defined at 3168 ft^2 which, for each 1/10th mile pavement segment, is equivalent to 50% of the total surface area. The two alternatives to assign deduct points for alligator cracking in flexible pavements are presented below.

Alternative One. This alternative is based on the sum of low, medium, and high severity levels alligator cracking. Such sum would substantially decrease the variability of each severity level. The deduct points could be calculated using equation (83). The results are listed and shown in Table 65 and Figure 94.

$$DP = 3168 * \frac{C^{0.7125}}{16220} \tag{83}$$

Where, DP equals deduct points, C equals the sum of low, medium, and high severity alligator cracks.

Table 65

Existing high severity level deduct points and the recommended deduct points based on the sum of all severity levels, flexible pavements

Extent (ft^2)	0	51	701	1301	2401	3168	9999.99
Existing deduct points for high severity level	0	1	29	43	50	61	61
Recommended deduct points	0	2	21	32	50	61	61

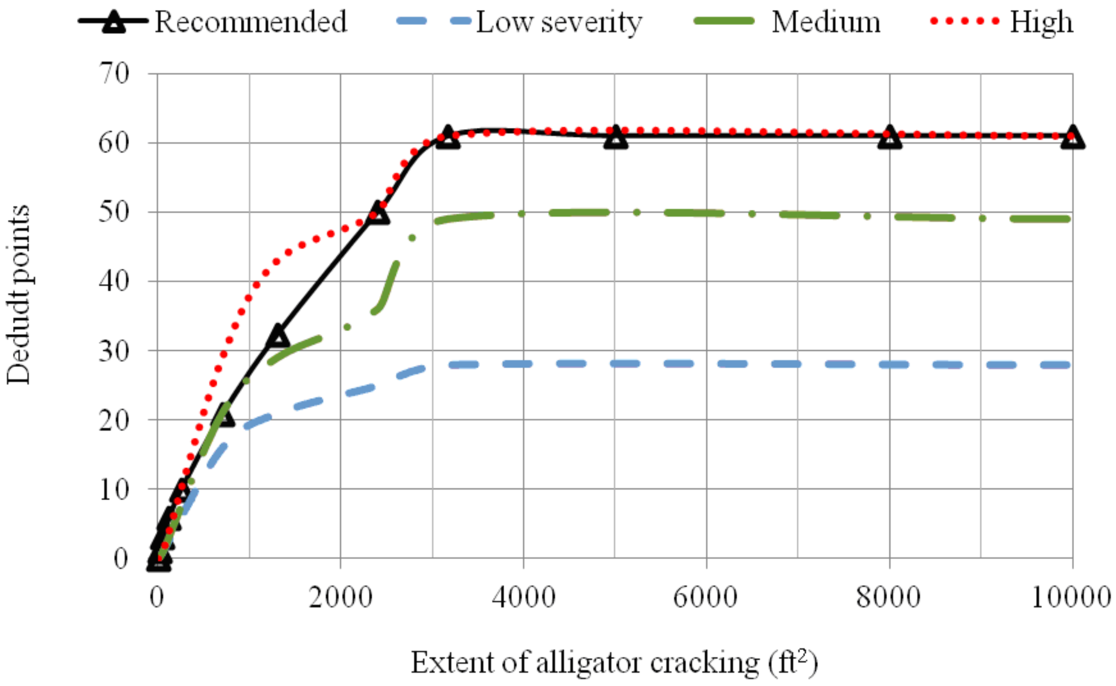


Figure 94

Existing and recommended deduct points for alligator cracking, alternative 1

Alternative Two. This alternative is based on the individual low, medium, and high severity levels alligator cracking. The deduct points, for each severity level, could be calculated using equation (84) and the overall deduct points for a given 1/10th mile pavement segment is given in equation (85). The results are shown in Figure 95 and listed in Table 66. The dashed lines in Figure 95 and the shaded areas in Table 66 address the existing DOTD deduct points.

$$DP_i = SL_i \left(3168 * \frac{C^{0.7125}}{16220} \right) \tag{84}$$

$$DP_{\text{pavet segment}} = \left(DP_{\text{low severity}} + DP_{\text{medium severity}} + DP_{\text{high severity}} \right) \leq 100 \tag{85}$$

Where, SL_i equals severity level, SL_i equals 0.556 for low severity, 0.833 for medium severity, and 1.0 for high severity.

For each 1/10th mile pavement segment, the limitation on the sum of the deduct points of 100 represents the maximum possible deduct points. The reason is that the DOTD distress index is based on a scale from zero to one hundred.

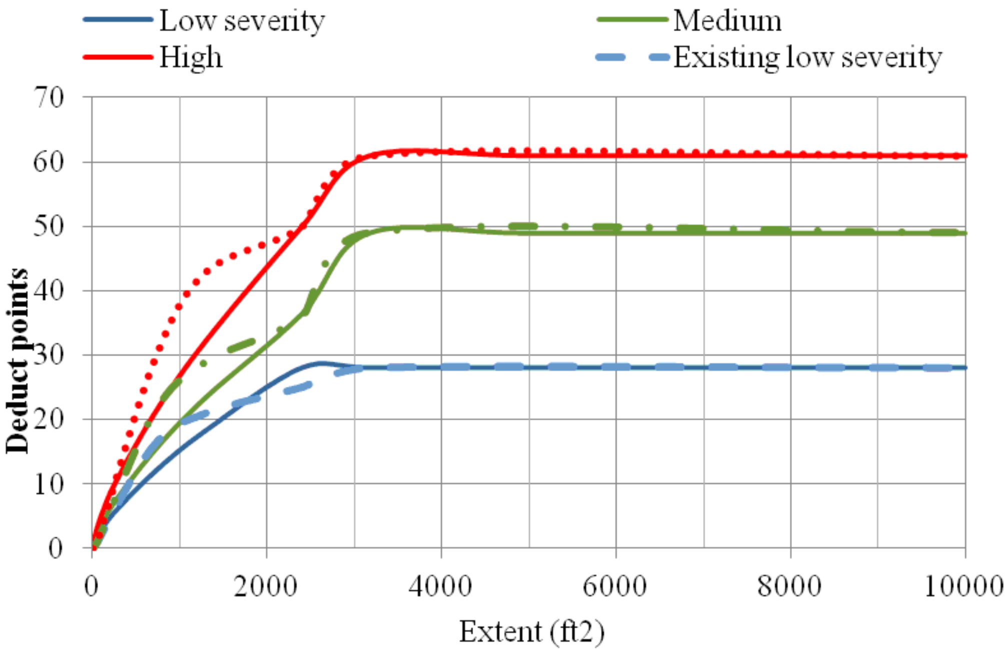


Figure 95

Existing and recommended deduct points for each severity level alligator cracking in flexible pavements, alternative 2

Table 66

Existing (shaded areas) and recommended deduct points for low, medium and high severity alligator cracking in flexible pavements, alternative 2

Severity level	Status	Extent (ft^2)						
		0	51	701	1301	2401	3168	9999.99
Low	Existing	0	1	16	21	25	28	28
	Recommended	0	2	12	18	28	28	28
Medium	Existing	0	1	21	29	36	49	49
	Recommended	0	2	15	24	36	49	49
High	Existing	0	1	29	43	50	61	61
	Recommended	0	3	21	32	50	61	61

Random, Transverse, and Longitudinal Cracking in Flexible and Composite Pavements

Since random cracking in flexible and composite pavements is the sum of transverse and longitudinal cracking, the materials presented below apply to the three cracking types and to both flexible and composite pavements.

Alternative One. This alternative is based on the sum of low, medium, and high severity levels random cracking. Such sums would substantially decrease the variability of each severity level. The deduct points could be calculated using equation (86). The results are shown in Figure 96 and listed in Table 67.

$$DP = 1056 * \frac{RC^{0.7125}}{10000} \tag{86}$$

Where, DP equals deduct points, RC equals the sum of low, medium, and high severity random cracking

Alternative Two. This alternative is based on the individual low, medium, and high severity levels random cracking. The deduct points for each severity level could be calculated using equation (87) and the overall deduct points for a given 1/10th mile pavement segment is given in equation (88). The results are shown in Figure 96 and listed in Table 67. The dashed lines in Figure 96 and the shaded areas in Table 67 address the existing DOTD deduct points.

$$DP_i = SL_i \left(1056 * \frac{RC^{0.7125}}{10000} \right) \tag{87}$$

$$DP_{\text{pavet segment}} = \left(DP_{\text{lowseverity}} + DP_{\text{mediumseverity}} + DP_{\text{highseverity}} \right) \le 100 \tag{88}$$

Where, SL_i equals severity level; SL_i equals 0.556 for low severity, 0.833 for medium severity, and 1.0 for high severity

Table 67

Existing deduct points for high severity random cracking in flexible and composite pavements and the recommended deduct points based on the sum of all severity levels

Extent (ft^2)(Flexible)	0	31	301	1601	5001	6001	9999.99
Existing deduct points for high severity level (Flexible)	0	1	26	28	42	48	48
Extent (ft^2) (Composite)	0	51	326	901	2001	6001	9999.99
Existing deduct points for high severity level (Composite)	0	1	32	40	55	70	70
Extent (ft^2) (Recommended for both Flexible and Composite)	0	31	301	1601	5001	6001	9999.99
Recommended deduct points (Both Flexible and Composite)	0	2	10	34	61	61	61

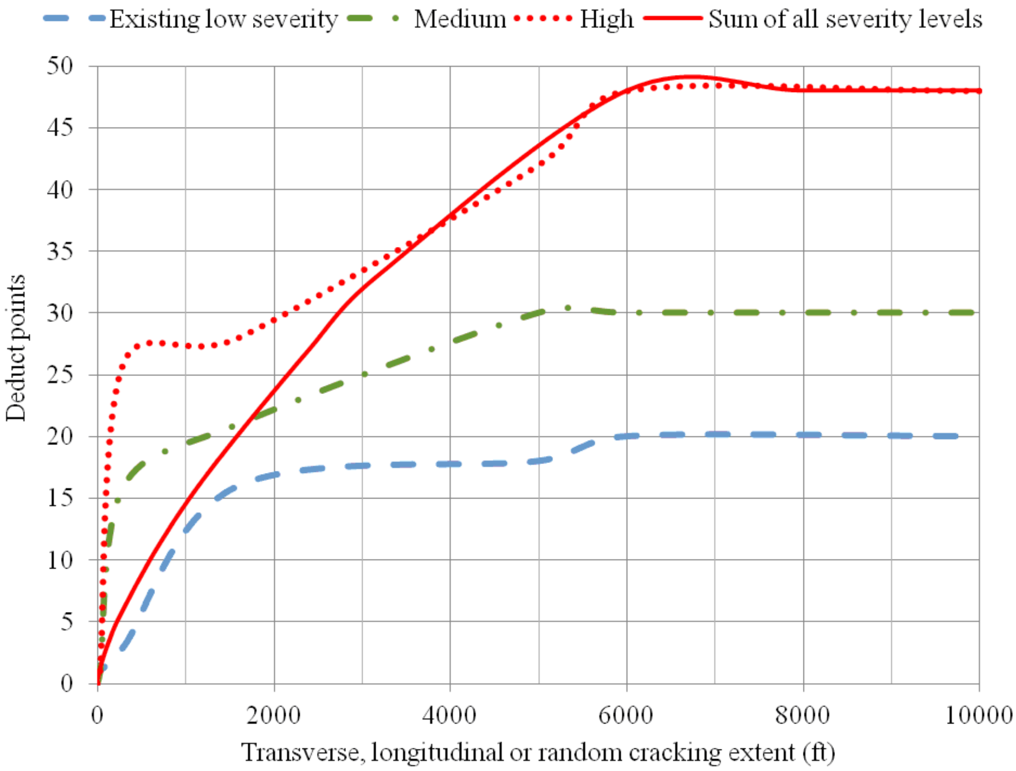


Figure 96
Existing and recommended deduct points for random, transverse, and longitudinal cracking in flexible and composite pavements, alternative 1

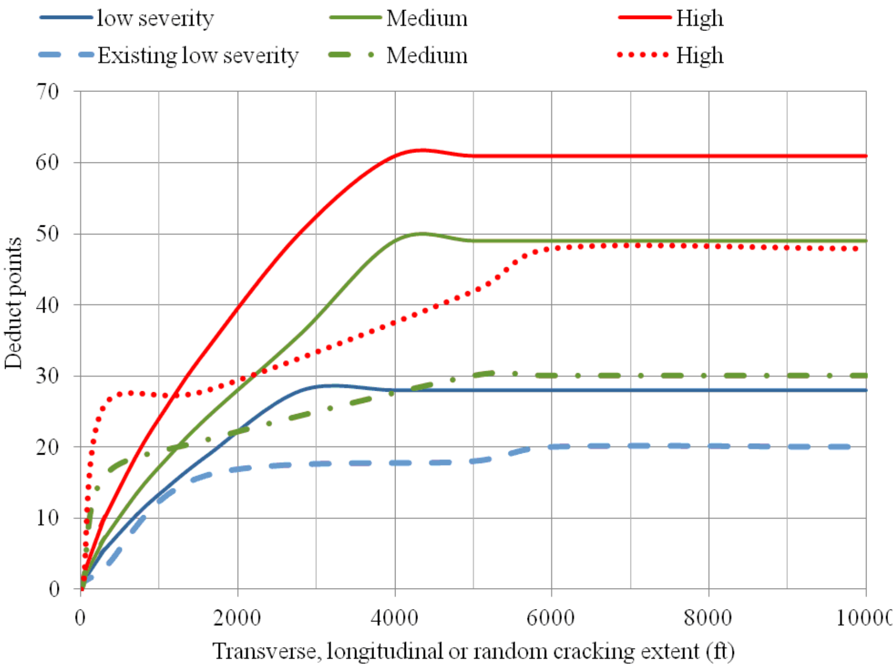


Figure 97

Existing (dashed lines) and recommended (solid lines) deduct points for each severity level random cracking in flexible pavements, alternative 2

Table 68

Existing (shaded area) and recommended deduct points for low, medium and high severity random cracks in flexible pavements, alternative 2

Severity level	Status	Extent (ft^2)						
		0	31	301	1601	5001	6001	9999.99
Low	Existing	0	1	3	16	18	20	20
	Recommended	0	1	6	19	28	28	28
Medium	Existing	0	1	16	26	35	46	46
	Recommended	0	2	15	24	49	49	49
High	Existing	0	1	26	28	42	48	48
	Recommended	0	3	21	32	50	61	61

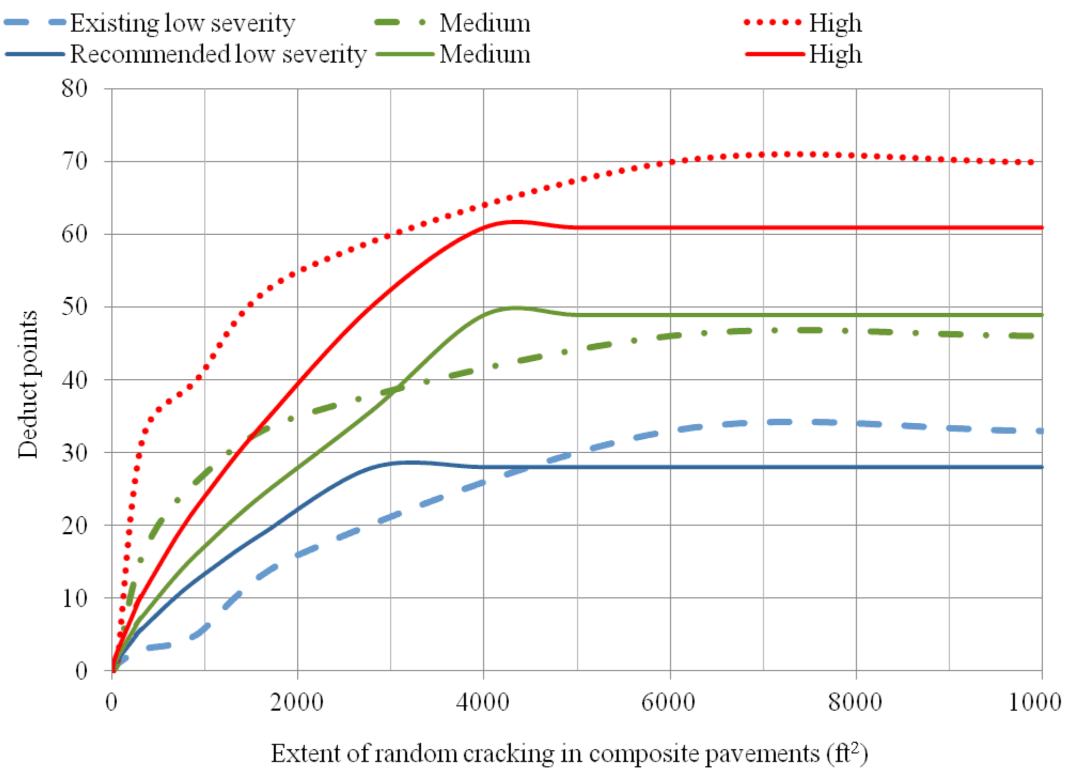


Figure 98
Existing deduct points (shaded lines) and recommended deduct points (solid lines) for each random cracking severity level in composite pavements

Table 69
Existing (shaded area) and recommended deduct points for low, medium and high severity random cracks in composite pavements, alternative 2

Severity level	Status	Extent (ft^2)						
		0	51	326	901	2001	6001	9999.99
Low	Existing	0	1	3	5	16	33	33
	Recommended	0	1	6	19	28	28	28
Medium	Existing	0	1	16	26	35	46	46
	Recommended	0	2	15	24	49	49	49
High	Existing	0	1	32	40	55	70	70
	Recommended	0	3	21	32	50	61	61

Patching in Flexible and Composite Pavements

Like the alligator and random cracking, two alternatives are presented herein; the first is based on the sum of all severity patching and the second on the individual severity level.

Alternative One. This alternative is based on the sum of low, medium, and high severity levels patching. Such sums would substantially decrease the variability of each severity level. The deduct points could be calculated using equation (89). The results are shown in Figure 99 and listed in Table 70.

$$DP = 3168 * \frac{P^{0.7125}}{16220} \qquad (89)$$

Where DP equals deduct points, P equals the sum of low, medium, and high severity patching

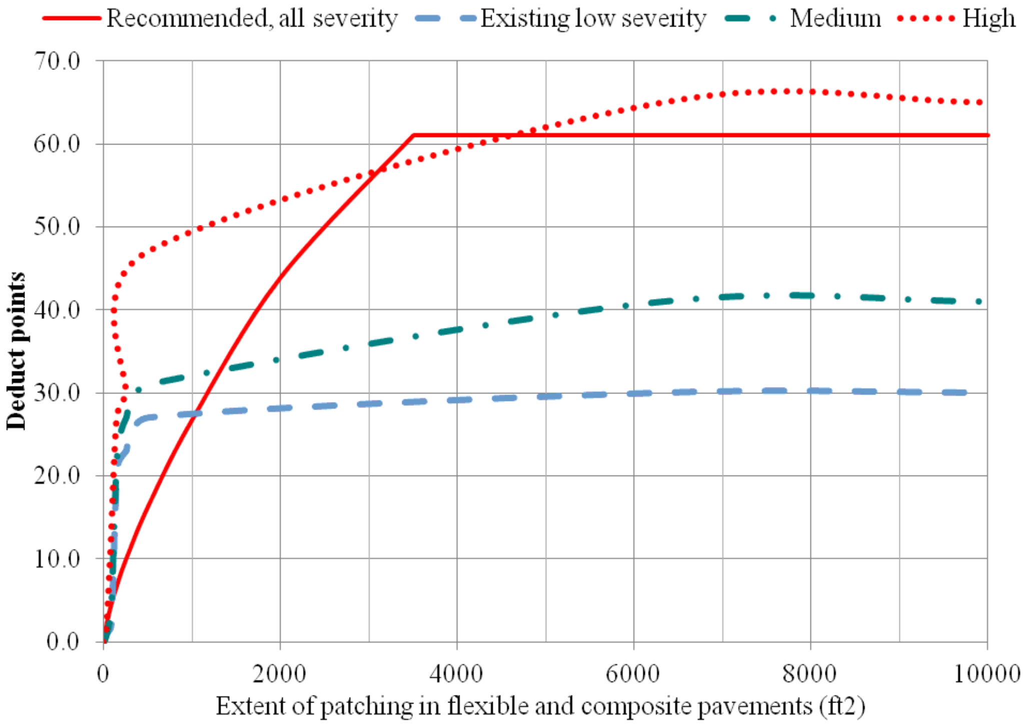


Figure 99

Existing and recommended deduct points for patching in flexible and composite pavements, alternative 1

Table 70
Existing deduct points for high severity patching in flexible and composite pavements and the recommended deduct points based on the sum of all severity levels

Extent (ft^2)	0	31	81	151	251	501	6336	9999.99
Existing deduct points for high severity level	0	1	11	27	30	47	65	65
Recommended deduct points	0	2	5	7	10	16	61	61

Alternative Two. This alternative is based on the individual low, medium, and high severity levels patching of flexible and composite pavements. The deduct points for each severity level could be calculated using equation (90) and the overall deduct points for a given 1/10th mile pavement segment is given in equation (91). The results are shown in Figure 100 and listed in Table 71. The dashed lines in Figure 100 and the shaded areas in Table 71 address the existing DOTD deduct points.

$$DP_i = SL_i\left(3168 * \frac{P^{0.7125}}{16220}\right) \tag{90}$$

$$DP_{\text{pavet segment}} = \left(DP_{\text{low severity}} + DP_{\text{medium severity}} + DP_{\text{high severity}}\right) \leq 100 \tag{91}$$

Where, SL_i equals severity level; SL_i equals 0.556 for low severity, 0.833 for medium severity, and 1.0 for high severity.

Table 71
Existing (shaded area) and recommended deduct points for low, medium and high severity patching in flexible and composite pavements, alternative 2

Severity level	Status	Extent (ft^2)							
		0	31	81	151	251	501	6336	9999.99
Low	Existing	0	1	2	21	23	27	30	30
	Recommended	0	1	3	4	6	9	28	28
Medium	Existing	0	1	4	23	27	31	41	41
	Recommended	0	2	3	5	7	12	49	49
High	Existing	0	1	11	27	30	47	65	65
	Recommended	0	2	5	7	10	16	61	61

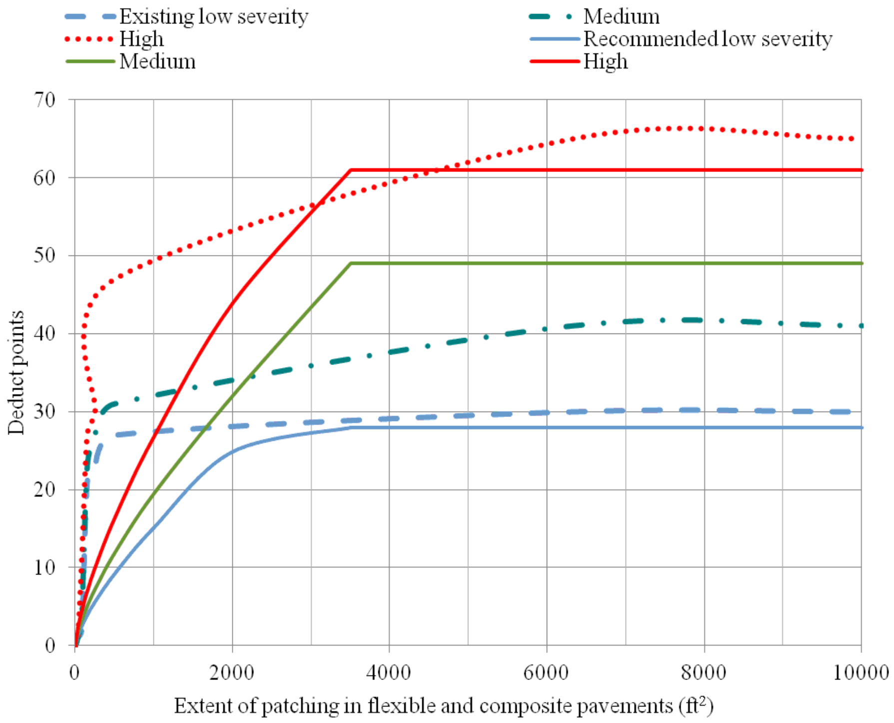


Figure 100

Existing deduct points (shaded lines) and recommended deduct points (solid lines) for each patching severity level in flexible and composite pavements

Transverse Cracking in Jointed Concrete Pavements

Once again two alternatives for calculating the deduct points for transverse cracking in jointed concrete pavements (JCP) are presented in this section. The first alternative is based on the sum of the transverse cracks in all severity levels. The second is based on the individual severity level. Recall that the saturation level of transverse cracking in JCP is 2900 ft.. Assuming each transverse crack is 12 ft. long yields 242 cracks. For 1/10th mile pavement segment and for 16 ft. joint spacing, this amounts to about 7 cracks per slab. The recommended transverse crack saturation level is 400 ft., which is equal to about 33 cracks or 1 crack in each of the 33 slabs (100% cracking) along the 1/10th mile pavement segment. Based on the recommended transverse crack saturation level, the two alternatives for the deduct points were developed and are presented below.

Alternative One. This alternative is based on the sum of low, medium, and high severity levels transverse cracking. Such sums would substantially decrease the variability of each severity level. The deduct points could be calculated using equation (92). The results are shown in Figure 101 and listed in Table 72.

$$\mathrm{DP} = 400 * \frac{TC^{0.7125}}{3500} \tag{92}$$

Where, DP equals deduct points, TC equals transverse crack (ft.)

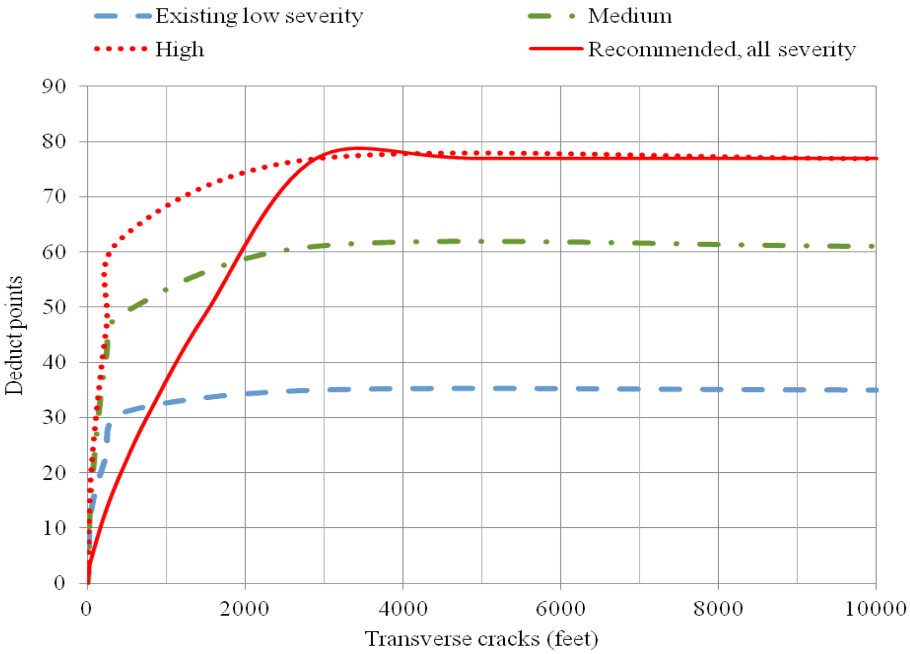


Figure 101

Existing and recommended deduct points for transverse cracking in JCP, alternative 1

Table 72

Existing deduct points for high severity transverse cracking in JCP and the recommended deduct points based on the sum of all severity levels

Extent (ft^2)	0	13	49	241	469	2900	9999.99
Existing deduct points for high severity level	0	1	20	46	63	77	77
Recommended deduct points	0	2	4	13	21	77	77

Alternative Two. This alternative is based on the individual low, medium, and high severity levels transverse cracking in jointed concrete pavements. The deduct points, for each severity level, could be calculated using equation (93) and the overall deduct points for a given 1/10th mile pavement segment is given in equation (94). The results are shown in Figure 100 and listed in Table 71. The dashed lines in Figure 102 and the shaded areas in Table 73 address the existing DOTD deduct points.

$$DP_i = SL_i\left(3168 * \frac{P^{0.7125}}{16220}\right) \tag{93}$$

$$DP_{pavet\ segment} = \left(DP_{low\,severity} + DP_{medium\,severity} + DP_{high\,severity}\right) \leq 100 \tag{94}$$

Where, SL_i equals severity level; SL_i equals 0.556 for low severity, 0.833 for medium severity, and 1.0 for high severity.

Table 73

Existing (shaded area) and recommended deduct points for low, medium and high severity transverse cracks in JCP, alternative 2

Severity level	Status	Extent (ft)						
		0	13	49	241	469	2900	9999.99
Low	Existing	0	1	13	23	31	35	35
	Recommended	0	1	2	7	12	35	35
Medium	Existing	0	1	16	41	49	61	61
	Recommended	0	1	4	11	18	61	61
High	Existing	0	1	20	46	63	77	77
	Recommended	0	2	4	13	21	77	77

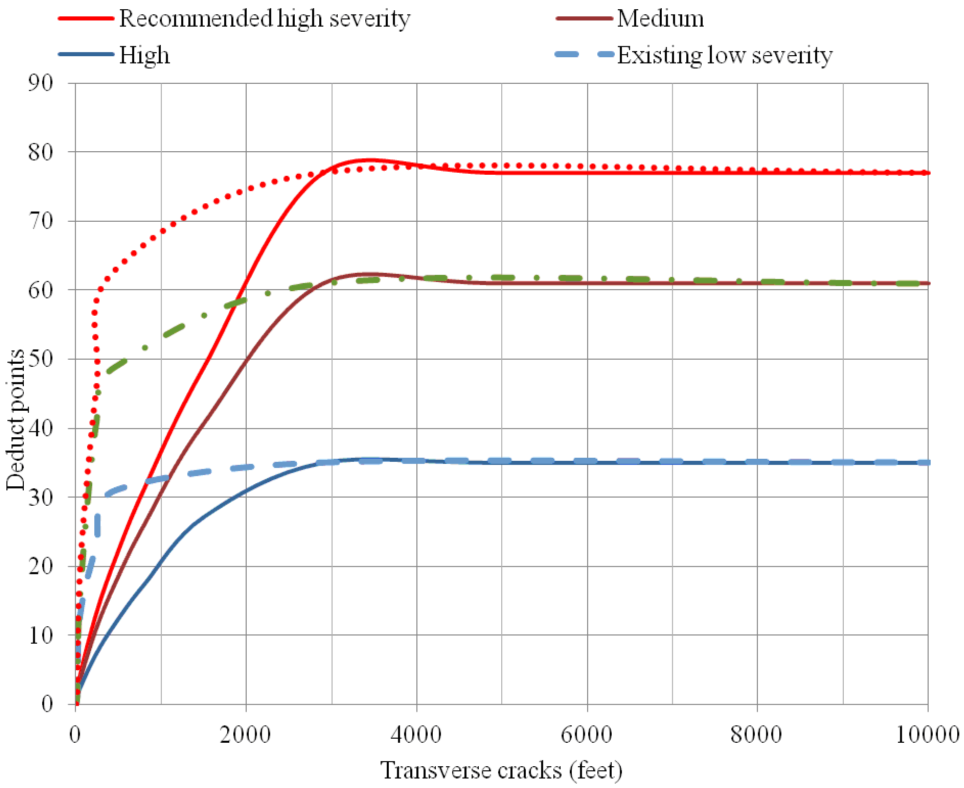


Figure 102

Existing deduct points (shaded lines) and recommended deduct points (solid lines) for each transverse cracking severity level in JCP, alternative 2

Longitudinal Cracking in Jointed and Continuously Reinforced Concrete Pavements

The existing longitudinal cracking saturation level is 1000 ft.; it is slightly modified herein to an even 200% cracking or 1056 ft. of longitudinal cracking in 1/10th mile pavement segment. Two deduct point alternatives were developed and are presented below. The first alternative is based on the sum of the transverse cracks in all severity levels. The second is based on the individual severity level.

Alternative One. This alternative is based on the sum of low, medium, and high severity levels transverse cracking. Such sums would substantially decrease the variability of each severity level. The deduct points could be calculated using equation (95). The results are shown in Figure 103 and listed in Table 74.

$$DP_i = SL_i\left(3168 * \frac{P^{0.7125}}{16220}\right) \tag{95}$$

Where, DP equals deduct points, LC equals longitudinal crack (ft.)

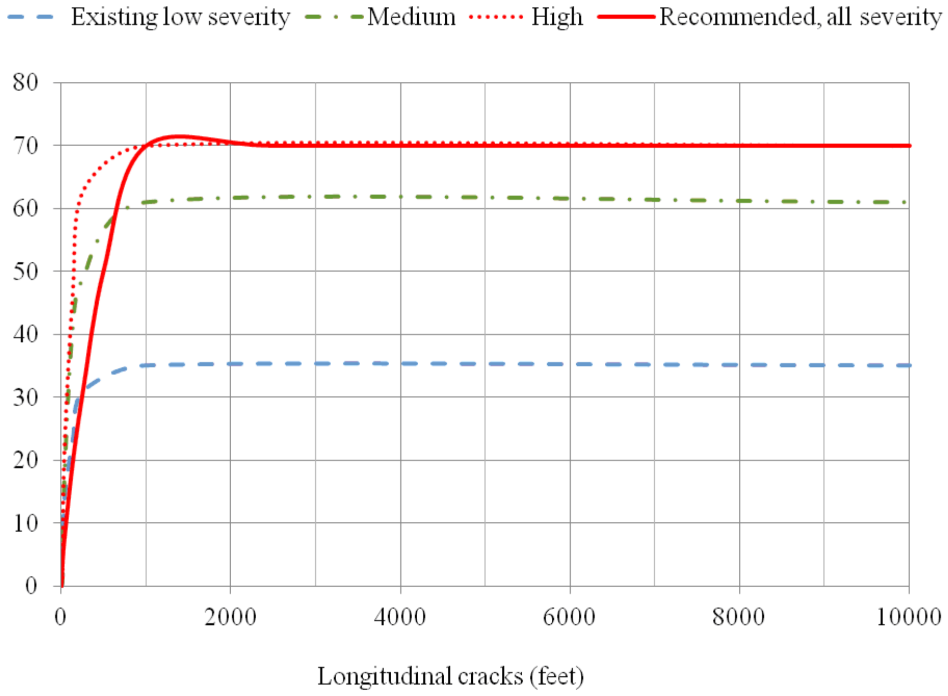


Figure 103
Existing and recommended deduct points for longitudinal cracking in JCP and CRC, alternative 1

Table 74
Existing deduct points for high severity longitudinal cracking in JCP and CRC pavements and the recommended deduct points based on the sum of all severity levels

Extent (ft^2)	0	11	31	131	261	1000	9999.99
Existing deduct points for high severity level	0	1	20	46	63	70	70
Recommended deduct points	0	3	7	19	32	70	70

Alternative Two. This alternative is based on the individual low, medium, and high severity levels transverse cracking in jointed concrete pavements. The deduct points for each severity level could be calculated using equation (96) and the overall deduct points for a given 1/10th mile pavement segment is given in equation (97). The results are shown in Figure 104 and listed in Table 75. The dashed lines in Figure 102 and the shaded areas in Table 73 address the existing DOTD deduct points.

$$DP_i = SL_i\left(6000 * \frac{P^{0.7125}}{10000}\right) \tag{96}$$

$$DP_{\text{pavet segment}} = \left(DP_{\text{lowseverity}} + DP_{\text{mediumseverity}} + DP_{\text{highseverity}}\right) \leq 100 \tag{97}$$

Where, SL_i equals severity level; SL_i equals 0.556 for low severity, 0.833 for medium severity, and 1.0 for high severity

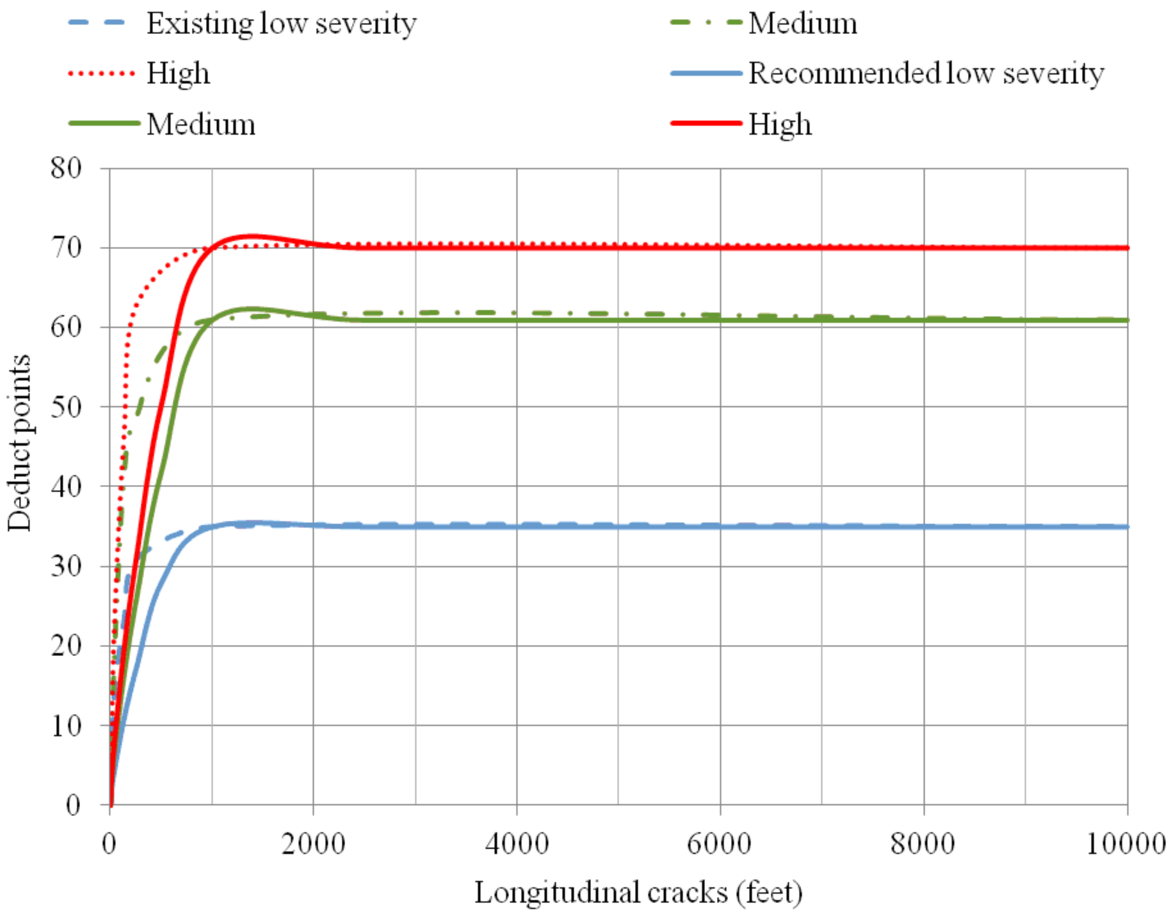


Figure 104

Existing deduct points (shaded lines) and recommended deduct points (solid lines) for each longitudinal cracking severity level in JCP and CRC, alternative 2

Table 75
Existing (shaded area) and recommended deduct points for low, medium and high severity longitudinal cracks in JCP and CRC, alternative 2

Severity level	Status	Extent (ft)						
		0	11	31	131	261	1000	9999.99
Low	Existing	0	1	13	23	31	35	35
	Recommended	0	1	2	7	12	35	35
Medium	Existing	0	1	16	41	49	61	61
	Recommended	0	1	4	11	18	61	61
High	Existing	0	1	20	46	63	70	70
	Recommended	0	2	4	13	21	77	77

Patching in JCP and CRC

Like patching in flexible and composite pavements, the recommended patching saturation point is 50% of the surface area of a 1/10th mile pavement segment or 3168 ft^2 of patching. Two alternatives are presented herein; the first is based on the sum of all severity patching and the second on the individual severity level.

Alternative One. This alternative is based on the sum of low, medium, and high severity levels patching. Such sums would substantially decrease the variability of each severity level. The deduct points could be calculated using equation (98). The results are shown in Figure 105 and listed in Table 76.

$$DP = 3168 * \frac{P^{0.7125}}{16220} \tag{98}$$

Where, DP equals deduct points, P equals the sum of low, medium, and high severity patching.

Table 76
Existing deduct points for high severity patching in JCP and CRC pavements and the recommended deduct points based on the sum of all severity levels

Extent (ft^2)	0	31	81	151	251	501	6336	9999.99
Existing deduct points for high severity level	0	1	11	20	35	47	65	65
Recommended deduct points	0	4	9	13	19	32	65	65

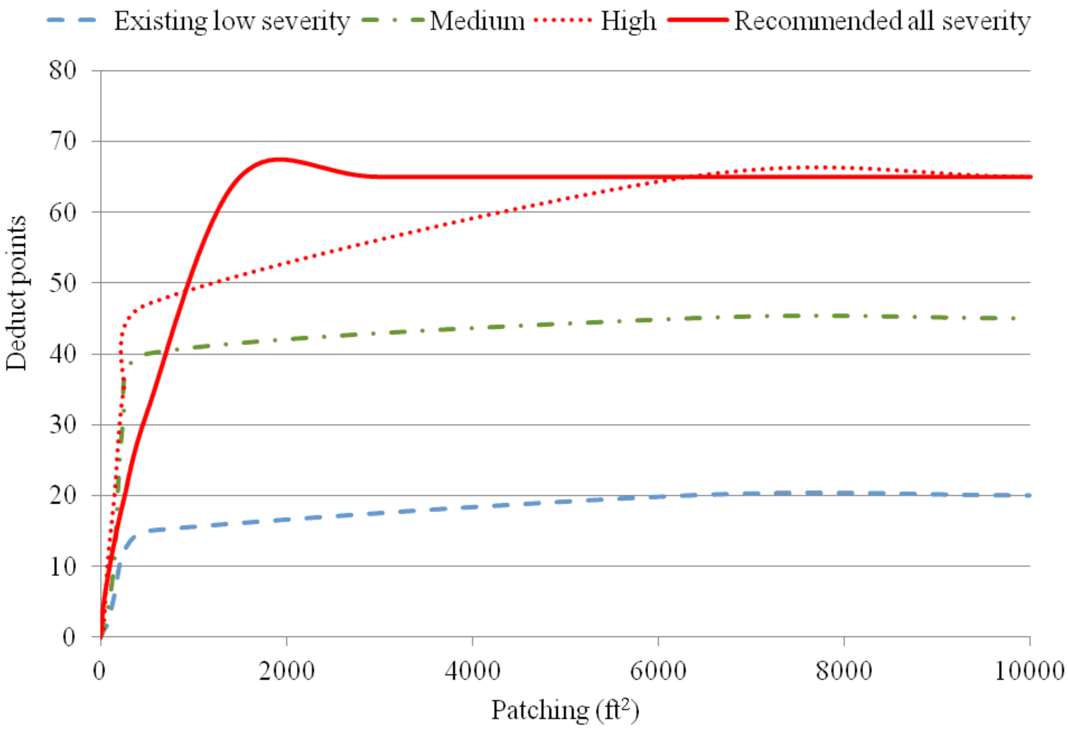


Figure 105

Existing and recommended deduct points patching in JCP and CRC pavements, alternative 1

Alternative Two. This alternative is based on the individual low, medium, and high severity levels patching of JCP and CRC pavements. The deduct points, for each severity level, could be calculated using equation (99) and the overall deduct points for a given 1/10th mile pavement segment is given in Equation (100). The results are shown in Figure 106 and listed in Table 77. The dashed lines in Figure 106 and the shaded areas in Table 77 address the existing DOTD deduct points.

$$DP_i = SL_i \left(3168 * \frac{P^{0.7125}}{16220} \right) \qquad (99)$$

$$DP_{pavet\ segment} = \left(DP_{lowseverity} + DP_{mediumseverity} + DP_{highseverity} \right) \leq 100 \qquad (100)$$

Where, SL_i equals severity level; SL_i equals 0.556 for low severity, 0.833 for medium severity, and 1.0 for high severity.

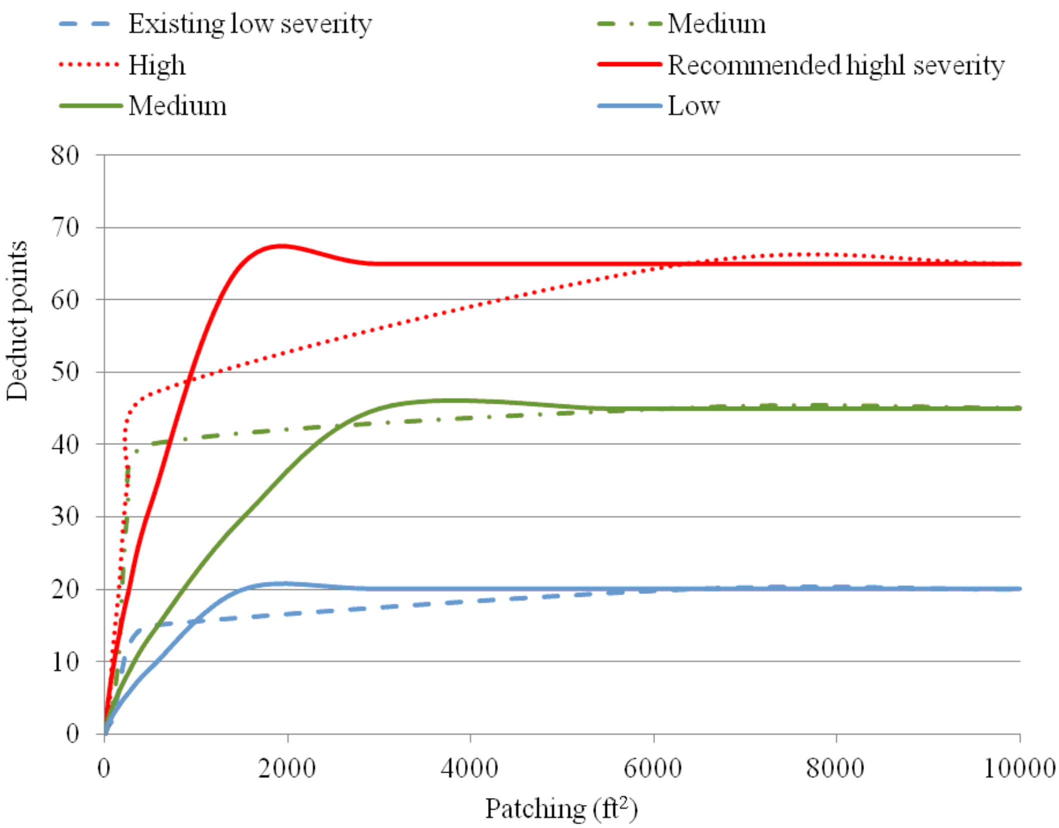


Figure 106

Existing deduct points (shaded lines) and recommended deduct points (solid lines) for each patching severity level in JCP and CRC, alternative 2

Table 77

Existing (shaded area) and recommended deduct points for low, medium and high severity patching in JCP and CRC, alternative 2

Severity level	Status	Extent (ft^2)							
		0	31	81	151	251	501	6336	9999.99
Low	Existing	0	1	2	6	12	15	20	20
	Recommended	0	1	2	4	6	9	20	20
Medium	Existing	0	1	4	11	31	40	45	45
	Recommended	0	2	4	6	8	14	45	45
High	Existing	0	1	11	20	35	47	65	65
	Recommended	0	4	9	13	19	32	65	65

Treatment Triggers and Resets

General

For various pavement treatment types of flexible, composite, jointed concrete pavements (JCP), and continuously reinforced concrete pavement (CRC) pavements and for four road classes, the existing Louisiana trigger values based on the actual pavement condition and distress and on the deduct values are listed in state -of-the-practice section of this report

These trigger values were calibrated based on the following two criteria:

1. Safety based on hydroplaning potential for rut depth only
2. The DOTD state -of-the-practice and the resulting pavement performance (the benefits of the treatments)

The results are presented in the next subsections.

Calibration of the Rut Depth Trigger Values for Flexible and Composite Pavements

Once again, the rut depth trigger values were analyzed based on hydroplaning potential and the DOTD state -of-the-practice. The results are presented and discussed in the next two subsections.

Hydroplaning Potential. The hydroplaning potential is a complex phenomenon that is a function of several variables including:

1. The depth of the standing water, which is a function of the rut depth, the pavement crown or cross slope, and the width of the rut channel.
2. The vehicle speed; in general, the hydraulic potential for vehicles traveling at 45 mile per hour or slower is almost zero.
3. The tire inflation pressure and the tire pavement contact area.
4. The water density, which is a function of the water temperature and debris such as sand, salt, and oil contaminant.
5. Tire and wheel moment of inertia.
6. The drag due to water displacement.

In general, for an average weight of passenger vehicles, an average tire thread, and an average speed of 45 to 55 mile per hour, the hydroplaning threshold is about 0.4-in. of standing water. As the thickness of the standing water increases above 0.4-in, the hydroplaning potential increases *[29], [30], [31], [32], [33], [34]*. Figure 107 through Figure 110 depict the depth of the standing water in the rut channel as a function of the width of the rut channel and the pavement crown (cross-slope). The depths of the standing water in Figure 107 through Figure 110 were calculated using rut depths of 0.625-in., 0.5625-in., 0.5-in., and 0.375-in., respectively. The hydroplaning threshold of 0.4-in. deep standing water for 55 mile per hour speed is also shown in Figure 107 through Figure 109. On the other hand, the hydroplaning threshold of 0.3-in. deep standing water shown in Figure 110 was estimated based on actual vehicle speed between 70 and 75 miles per (1-6). It should be noted that, for all four figures, the depths of the standing water were calculated for rut depth channel width of 1, 2, 3, 4, and 5 ft. The calculations of the standing water depths were based on the crown/cross slope of the pavement surface, the rut depths, and the rut channel width as illustrated in Figure 111.

It should be noted that narrow rut channels (1 to 2 ft.) indicate that the rut problem is mainly in the HMA layer, 2 to 4 ft. in the HMA, base and subbase layers, and more than 4 ft.; the rut problem could be in all layers and the roadbed soils.

The data in Figure 107 and Figure 108 indicate that at 0.625 and 0.5625-in. rut depths, the hydroplaning potential is relatively high especially if the rut channel is narrow (up to 2 ft. wide) and the posted speed limit is higher than 45 mile per hour. Therefore, it is strongly recommended that DOTD modify the existing trigger values. The recommended modifications are listed in Table 78 and are strictly based on hydroplaning potential and the safety of the traveling public. If the posted speed limit on local roads is less than or equal to 45 mile per hour then the existing trigger values are safe and within the hydroplaning safety zone. Please note that the recommendations are based on cross slope (crown) of 2%.

Calibration of the Trigger Values based on the DOTD State-of-the-Practice. The calibration of the DOTD trigger values are accomplished herein based on the distress type and road class. For each distress type, the pavement performances before and after treatment were analyzed using the DOTD actual pavement distress and condition data and the deduct points. The results are presented in treatment transition matrices and are discussed below:

1. Rut Depth

The calibration of the trigger values for rut depths are accomplished for Interstates, Arterials, and Collectors. The calibrated trigger points for collector apply to the local roads as well.

a) Flexible and Composite Interstates

Unfortunately, the DOTD database for 2-in., 3.5-in. and more than 4-in. HMA overlay treatments of flexible and composite Intestate pavements does not contain statistically significant data to be used in the calibration of the rut depth trigger values. The database contains only two pavement projects, totaling less than 5 miles for 2.0-in. HMA overlay as listed in Table 79 and Table 80, and less than 0.5 mile for 3.5-in. HMA overlay, and no projects for more than 4-in. HMA overlay. Therefore, the calibration of the rut depth trigger values for interstates are strictly based on the risk for hydroplaning potential as detailed above. The calibrated trigger values are presented in Table 81.

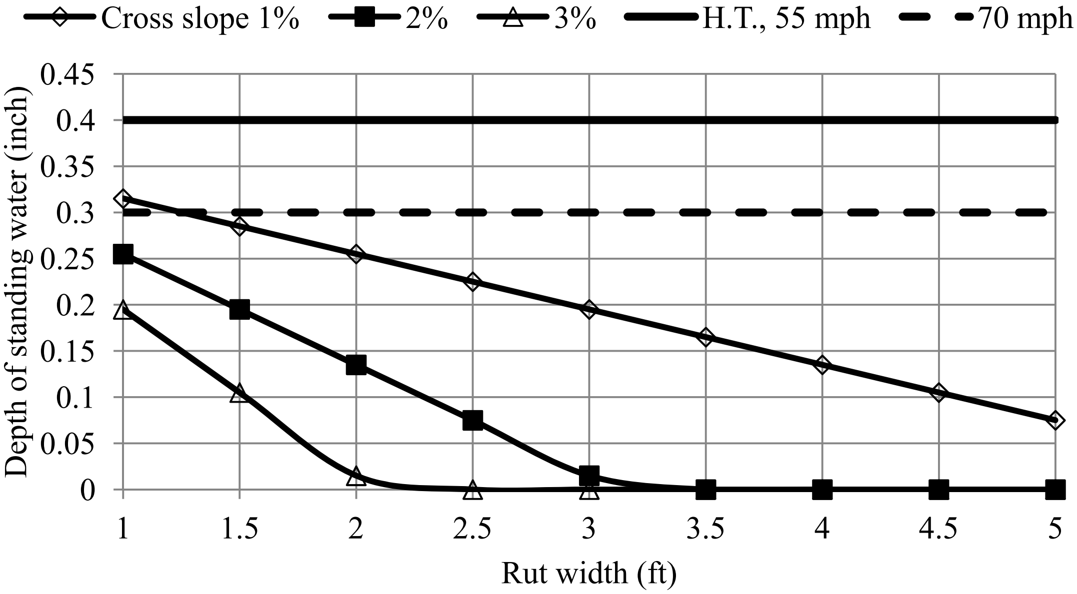


Figure 107
Depth of standing water as a function of rut width, rut depth of 0.375-in., and three cross slopes, hydroplaning thresholds (H.T.) for 55 and 70 mile per hour speeds

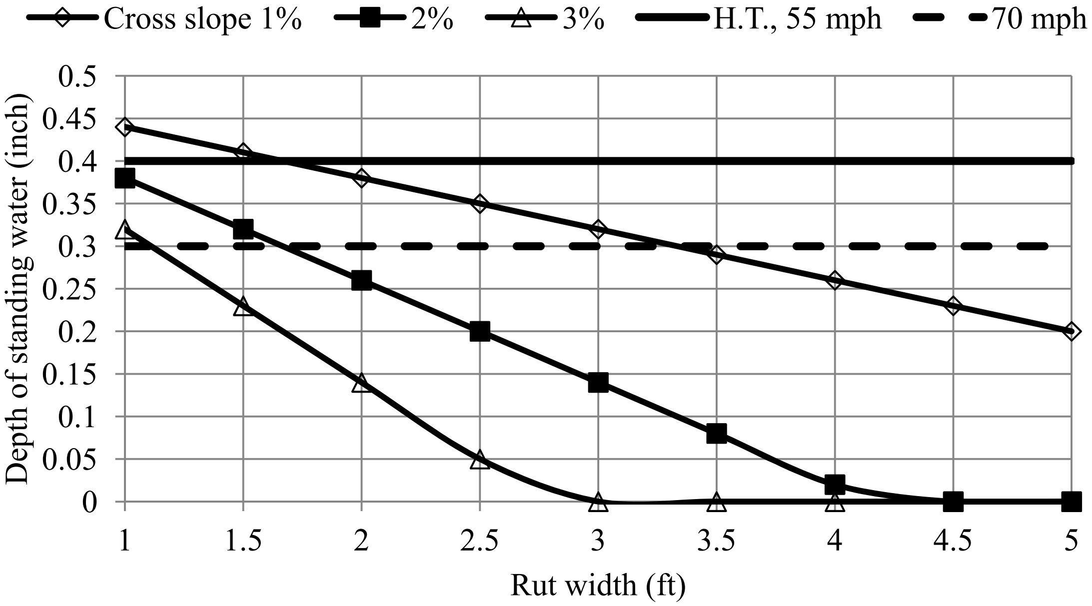


Figure 108
Depth of standing water as a function of rut width, rut depth of 0.5-in., and three cross slopes, hydroplaning thresholds (H.T.) for 55 and 70 mile per hour speeds

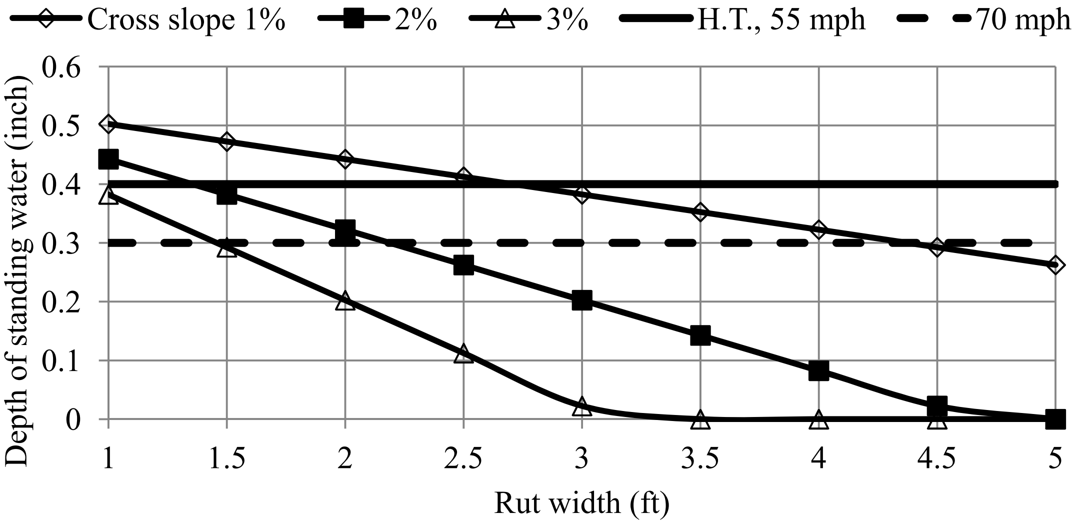


Figure 109
Depth of standing water as a function of rut width, rut depth of 0.5625-in., and three cross slopes, hydroplaning thresholds (H.T.) for 55 and 70 mile per hour speeds

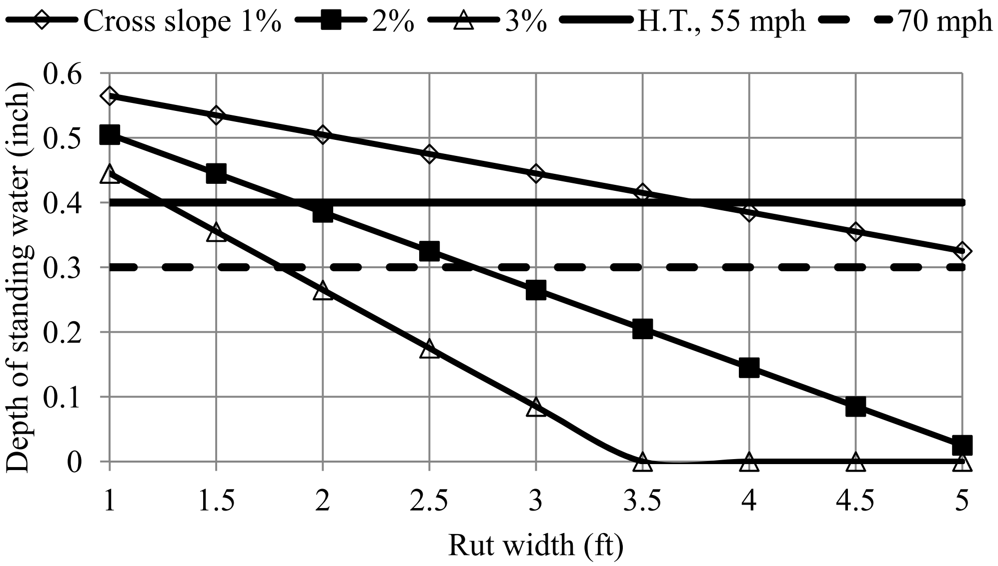


Figure 110
Depth of standing water as a function of rut width, rut depth of 0.625-in., and three cross slopes, hydroplaning thresholds (H.T.) for 55 and 70 mile per hour speeds

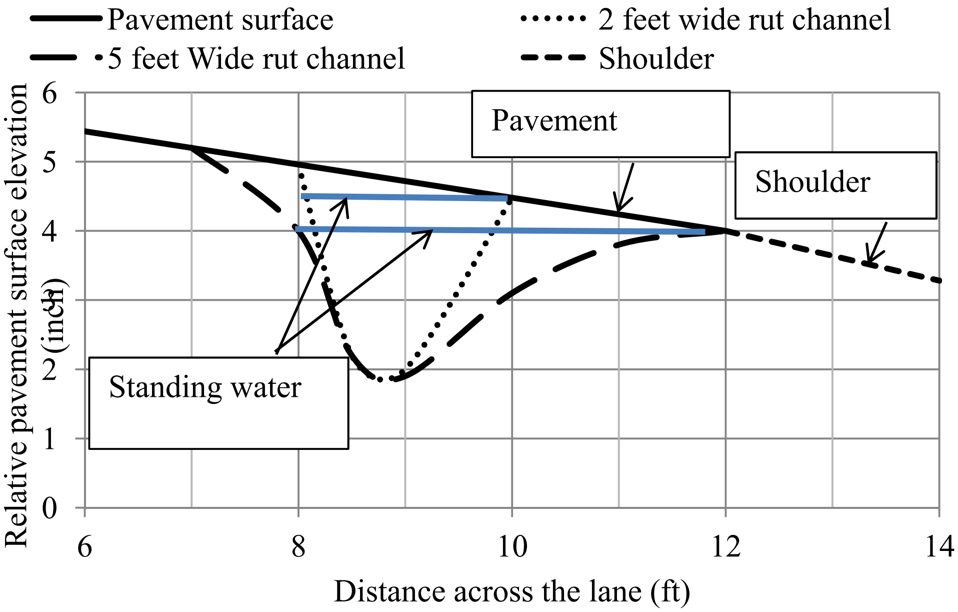


Figure 111
Pavement having 2% cross slope, 3% shoulder slope, the same rut depth (not to scale), rut channel widths of 2 and 5 ft., and different depths of standing water as indicated by the blue lines

Table 78
Recommended trigger values for rut depths in flexible and composite pavements based on hydroplaning potential and cross slope (crown) of 2%

Road class and rut depth, deduct points and rut depth index														
Pavement type		Interstate (70 mph)				Arterial (55 mph)[1]			Collector (55 mph)[2]			Local (55 mph)		
	HMA overlay thickness (in)	M.S.[3]	≤2”	>2-≤4”	>4”	<2”	2-4”	>4”	<2”	2-4”	>4”	<2”	2-4”	>4"
Flexible	Rut depth (in)	≥0.25to <0.35	0.35 to 0.5	0.35 to 0.5	0.35 to 0.5	0.375	0.45	0.5	0.375	0.45	0.5	0.375	0.45	0.5
	Deduct points	≥10 to <18	18 to 30	18 to 30	18 to 30	20	26	30	20	26	30	20	26	30
	Rut index	<82 to 90	82 to 70	82 to 70	82 to 70	80	74	70	80	74	70	80	74	70
Composite	Rut depth (in)	≥0.25to <0.35	0.35 to 0.5	0.35 to 0.5	0.35 to 0.5	0.375	0.45	0.5	0.375	0.45	0.5	-	-	-
	Deduct points	≥10 to <18	18 to 30	18 to 30	18 to 30	20	26	30	20	26	30	-	-	-
	Rut index	≤90 to <82	82 to 70	82 to 70	82 to 70	80	74	70	80	74	70	-	-	-
Flexible	Local (45 mph or less)													
	Rut depth (in)											0.5	0.5625	0.625
	Deduct points											30	35	40
	Rut index											70	65	60

[1] If the speed limit on some arterial roads is 70 mph, the trigger values for these arterial roads should be the same as the trigger values for Interstates

[2] If the speed limit on some collector roads is 70 mph, the trigger values for these collector roads should be the same as the trigger values for Interstates

[3] M.S. is microsurfacing

Table 79

Treatment transition matrix for 2-in. HMA overlay of flexible and composite Interstates based on the actual rut depth data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in)							
										0.02			
A	1	0 to 2	42	84	0.04	**0**	0	0	0	42	10	19	20
B	2	3 to 5	0	0		0	**0**	0	0	0			
C	3	6 to 10	4	8	0.07	0	0	**0**	0	4	10	12	20
D	4	11 to 15	0	0		0	0	0	**0**	0			
E	5	16 to 25	4	8	0.03	0	0	0	0	**4**	10	0	20
F	Total		50	100		0	0	0	0	50	10	17	20

Table 80

Treatment transition matrix for 2-in. HMA overlay of flexible and composite Interstates based on the DOTD deduct points for rut depth

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
										3.79			
A	1	0 to 2	43	100	30.64	**0**	0	0	0	43	10	19	20
B	2	3 to 5	0	0		0	**0**	0	0	0			
C	3	6 to 10	0	0		0	0	**0**	0	0			
D	4	11 to 15	0	0		0	0	0	**0**	0			
E	5	16 to 25	0	0		0	0	0	0	**0**			
F	Total		43	100		0	0	0	0	43	10	19	20

Table 81
Existing and calibrated Louisiana trigger values for rut depths in flexible and composite interstate pavements and the listed treatment types

Pavement distress and/or condition						
Pavement Type	Status of trigger values	Distress/condition type	Treatment type for flexible and composite Interstate			
			1(1)	2(2)	3(3)	4(4)
Flexible	Current trigger values	Rut depth (in)	>0.25 to ≤0.375	>0.375	-	-
		Indices	≥80 to <90	<80	-	-
	Calibrated trigger values	Rut depth (in)	≥0.25 to <0.35	0.35 to 0.5	0.35 to 0.5	0.35 to 0.5
		Indices[1]	>82 to ≤90	70 to 82	70 to 82	70 to 82
		Indices[2]	>82 to ≤90	70 to 82	70 to 82	70 to 82
Composite	Current trigger values	Rut depth (in)	>0.25 to ≤0.375	>0.375	-	-
		Indices	≥80 to <90	<80	-	-
	Calibrated trigger values	Rut depth (in)	≥0.25 to <0.35	0.35 to 0.5	0.35 to 0.5	0.35 to 0.5
		Indices[1]	>82 to ≤90	70 to 82	70 to 82	70 to 82
		Indices[2]	>82 to ≤90	70 to 82	70 to 82	70 to 82

Treatment	Treatment Type and Description
1(1)	Microsurfacing on Interstate
2(2)	Thin Overlay on Interstate (Cold Plane 2", put 2" back; 0-100 Square Yards Patching)
3(3)	Medium Overlay on Interstate (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-300 Square Yards Patching)
4(4)	Structural Overlay on Interstate (7" Overlay; 700 Square Yards Patching)

[1] Indices[1] equals Based on the existing DOTD deduct points

[2] Indices[2] equals Based on the recommended deduct points

*Values in parentheses represent composite treatments

b) Flexible and composite Arterial Roads

Like the Interstate system, the DOTD database for 2-in. HMA overlay does not contain statistically significant data to be used in the calibration of the rut depth trigger values. The database contains less than 10 miles of flexible and composite pavements that received 2.0-in. HMA overlay as listed in the treatment transition matrices of Table 82 and Table 83. The scenario, however, is much different for the 3.5-in. HMA overlay on flexible and composite arterial pavements. The database contains more than 30 miles of flexible and composite pavements that received 3.5-in. overlay. The treatment transition matrix based on the actual rut depth data and on the deduct points are listed in Table 84 and Table 85. Examination of the data listed in the two tables indicates that the rut depths of the treated pavement sections vary from 0.0 to more than 0.5-in. The benefit section of the tables indicates that the benefits of the 3.5-in. HMA overlay are the same and independent of the rut depths before treatment. The implication of this is that, the construction of the 3.5-in. HMA overlay did take care of all rut depths on equal footing. Therefore, the trigger values are not dependent on the rut depths before treatment; they are dependent on the safety of the traveling public (hydroplaning). Thus, the calibrated trigger values for flexible and composite arterial pavements are based on the hydroplaning potential. The calibrated trigger values are presented in two sets; one for 70 mph speed limit and the other for 55 mph. Both sets are included in Table 86.

c) Flexible and composite Collector and Local Roads

Table 87 and Table 88 provide the treatment transition matrices for 2-in. HMA overlays applied to flexible and composite collector roads. The results in Table 87 are based on the rut depth data of 41.4 miles (414 of 0.1 mile long pavement segments). Whereas, the results in Table 88 are based on the existing DOTD deduct points for rut depths of 21.6 miles (216 of 0.1 mile long pavement segments). The number of the 0.1 mile long pavement segments in each table reflects the number of segments that passed the two acceptance criteria. Unfortunately, only 0.6 mile of flexible local roads passed the two acceptance criteria. Nevertheless, the results in Table 87 and Table 88 indicate that the 2.0-in. overlay could be applied to any flexible pavement section having measurable rut depths without significantly affecting the pavements. Therefore, the trigger values for 2-in. HMA overlays on flexible and composite collector and local roads were calibrated based on hydroplaning potential only. It is important to note that the impact of the 2-in. HMA overlays on the pavement performance due to other distress types could be significantly different.

Table 89 and Table 90 provide the treatment transition matrices for 3.5-in. HMA overlays applied to flexible and composite collector roads. The results in Table 89 are based on the rut depth data of 142.4 miles (1424 of 0.1 mile long pavement segments). The results in Table 90 are based on the existing DOTD deduct points for rut depths along 31.3 miles (313 of 0.1 mile long pavement segments). Finally Table 91 and Table 92 provide similar results for flexible local roads that were subjected to 3.5-in. HMA overlays. Table 91 is based on the performance of 29.6 miles (296 of 0.1 mile pavement segments) while Table 92 on 5.2 miles.

Once again, the after treatment results listed in Table 89 through Table 92 are not dependent on the before treatment rut depths. That is the existing trigger values are neutral and do not impact the pavement performance relative to rutting. Therefore, the calibration of the trigger values for collector and local roads is mainly based on the hydroplaning potential.

Table 93 provides a list of the existing trigger values for rut depths and the calibrated values. All calibrated values are based on hydroplaning potential, 2% cross slope, and vehicle speed of 55 miles per hour.

2. Brief Discussion of the Results of all Road Class

Results of the analyses of rut depths and 2-in. and 3.5-in. overlays indicate that, at least six years after construction (three data collection cycles), the pavement performance relative to rutting is not affected by the levels of rut depth before treatment. Hence, the trigger deduct point values play no role in the after treatment pavement performance. These findings could be related to any combinations of various reasons including:

- Good to excellent quality assurance and quality control programs.
- Good to excellent construction practices.
- The overlays strengthen the pavement sections and substantially decreased the rutting potential.
- The rut problem was confined to the surface HMA course, which was milled.
- The time span of six years is not sufficient for the development of rut depth. Although, if a pavement section is prune to rutting, the rut will take place at an early age and the rate of rutting decreases over time.
- The selected treatments of 2.0-in. and 3.5-in. overlays could be based on other pavement distresses. The percent of each overlay project where the before treatment rut depth reached the trigger deduct points is very small. Hence, the action could have been dictated by other distress types.

3. The Calibrated Trigger Values

The calibrated trigger deduct point values are mainly based on hydroplaning potential, two percent cross slope or crown of the pavement section, and vehicle speed of 70 miles per hour for flexible and composite Interstate and arterial roads and 55 miles per hour for arterial, collector, and local roads.

Table 82
Treatment transition matrix for 2-in. HMA overlay of flexible and composite arterial roads based on the actual rut depth data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in)							
									0.07	0.03			
A	1	0 to 2	40	43	0.12	**0**	0	0	1	39	10	19	20
B	2	3 to 5	8	9	0.13	0	**0**	0	0	8	10	16	20
C	3	6 to 10	2	2	0.13	0	0	**0**	0	2	10	12	20
D	4	11 to 15	3	3	0.08	0	0	0	**0**	3	10	7	20
E	5	16 to 25	41	44	0.07	0	0	0	0	**41**	10	0	20
F	Total		94	100		0	0	0	1	93	10	10	20

Table 83

Treatment transition matrix for 2-in. HMA overlay of flexible and composite arterial roads based on the DOTD deduct points for rut depth

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
									6.17	3.66			
A	1	0 to 2	18	24	11.43	**0**	0	0	1	17	10	19	20
B	2	3 to 5	6	8	10.94	0	**0**	0	0	6	10	16	20
C	3	6 to 10	5	7	9.64	0	0	**0**	0	5	10	12	20
D	4	11 to 15	3	4	11.67	0	0	0	**0**	3	10	7	20
E	5	16 to 25	43	57	6.65	0	0	0	0	**43**	10	0	20
F	Total		75	100		0	0	0	1	74	10	7	20

Table 84
Treatment transition matrix for 3.5-in.HMA overlay of flexible and composite arterial roads based on the actual rut depth data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
							0.08	0.12	0.03	0.02			
A	1	0 to 2	109	31	0.12	**0**	0	1	2	106	10	19	20
B	2	3 to 5	20	6	0.11	0	**0**	0	0	20	10	16	20
C	3	6 to 10	20	6	0.12	0	0	**1**	0	19	10	11	19
D	4	11 to 15	62	18	0.09	0	0	1	**3**	58	9	6	19
E	5	16 to 25	143	40	0.09	0	1	0	0	**142**	10	0	20
F	Total		354	100		0	1	3	5	345	10	8	20

Table 85

Treatment transition matrix for 3.5-in. HMA overlay of flexible and composite arterial roads based on the DOTD **deduct points for rut depth**

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
							7.32	6.6	2.16	2.27			
A	1	0 to 2	80	30	11.61	**0**	0	2	2	76	10	19	20
B	2	3 to 5	21	8	10.49	0	**0**	0	0	21	10	16	20
C	3	6 to 10	23	9	10.25	0	0	**0**	0	23	10	12	20
D	4	11 to 15	51	19	6.44	0	0	4	**4**	43	9	6	19
E	5	16 to 25	94	35	7.88	0	1	0	0	**93**	10	0	20
F	Total		269	100		0	1	6	6	256	10	9	20

Table 86
Existing and calibrated Louisiana trigger values for rut depths in flexible and composite arterial pavements for the listed treatment types

Pavement distress and/or condition										
Pavement Type	Status of trigger values	Distress/condition type	Treatment type							
			Arterial 2, 70 mph				Arterial 1, 55 mph			
			5(5)	6(7)	7(8)	8(10)	5(5)	6(7)	7(8)	8(10)
Flexible	Current trigger values	Rut depth (in)	>0.25 to ≤0.563	>0.563	-	-	>0.25 to ≤0.563	>0.563	-	-
		Indices	≥65 to <90	<65	-	-	≥65 to <90	<65	-	-
	Calibrated trigger values	Rut depth (in)	≥0.25 to <0.35	0.35 to 0.5	0.35 to 0.5	0.35 to 0.5	>.375 to ≤.5	>.5 to .625		
		Indices[1]	>82 to ≤90	70 to 82	70 to 82	70 to 82	≥70 to <80	>60 to 70		
		Indices[2]	>82 to ≤90	70 to 82	70 to 82	70 to 82	≥70 to <80	>60 to 70		
Composite	Current trigger values	Rut depth (in)	>0.25 to ≤0.563	>0.563	-	-	>0.25 to ≤0.563	>0.563	-	-
		Indices	≥65 to <90	<65	-	-	≥65 to <90	<65	-	-
	Calibrated trigger values	Rut depth (in)	≥0.25 to <0.35	0.35 to 0.5	0.35 to 0.5	0.35 to 0.5	>.375 to ≤.5	>0.5 to .625		
		Indices[1]	>82 to ≤90	70 to 82	70 to 82	70 to 82	≥70 to <80	>60 to 70		
		Indices[2]	>82 to ≤90	70 to 82	70 to 82	70 to 82	≥70 to <80	>60 to 70		

Treatment	Treatment Type and Description
5(5)	Microsurfacing on Arterial
6(7)	Thin Overlay on Arterial (Cold Plane 2", put 2" back; 0-100 Square Yards Patching)
7(8)	Medium Overlay on Arterial (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-300 Square Yards Patching)
8(10)	Structural Overlay on Arterial (5.5" Overlay; 700 Square Yards Patching)

Indices[1] equals Based on the existing DOTD deduct points

Indices[2] equals Based on the recommended deduct points. *Values in parentheses represent composite treatments

Table 87

Treatment transition matrix for 2-in. HMA overlay of flexible and composite collector roads based on the rut depth data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
							0.05	0.1	0.02	0.03			
A	1	0 to 2	59	14	0.09	**0**	1	1	3	54	10	18	19
B	2	3 to 5	13	3	0.06	0	**0**	0	0	13	10	16	20
C	3	6 to 10	26	6	0.05	0	0	**0**	0	26	10	12	20
D	4	11 to 15	117	28	0.06	0	0	0	**0**	117	10	7	20
E	5	16 to 25	199	48	0.06	0	0	0	0	**199**	10	0	20
F	Total		414	100		0	1	1	3	409	10	6	20

Table 88

Treatment transition matrix for 2-in. HMA overlay of flexible and composite collector roads based on the DOTD deduct points

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in)							
							2.52	7.86	1.87	2.30			
A	1	0 to 2	47	22	10.37	**0**	1	1	2	43	10	18	19
B	2	3 to 5	12	6	6.37	0	**0**	0	0	12	10	16	20
C	3	6 to 10	13	6	5.10	0	0	**0**	0	13	10	12	20
D	4	11 to 15	23	11	6.88	0	0	0	**0**	23	10	7	20
E	5	16 to 25	121	56	5.74	0	0	0	0	**121**	10	0	20
F	Total		216	100		0	1	1	2	212	10	6	20

Table 89

Treatment transition matrix for 3.5-in. HMA overlay of flexible and composite collector roads based on the rut depth data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
						0.42		0.14		0.03			
A	1	0 to 2	370	26	0.09	**2**	0	2	0	366	10	19	20
B	2	3 to 5	54	4	0.07	0	**0**	0	0	54	10	16	20
C	3	6 to 10	74	5	0.06	0	0	**0**	0	74	10	12	20
D	4	11 to 15	217	15	0.06	0	0	0	**0**	217	10	7	20
E	5	16 to 25	709	50	0.06	0	0	0	0	**709**	10	0	20
F	Total		1424	100		2	0	2	0	1420	10	7	20

Table 90

Treatment transition matrix for 3.5-in. HMA overlay of flexible and composite collector roads based on the DOTD deduct points for rut depth

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in)							
						64.90	48.17	12.99		2.19			
A	1	0 to 2	80	26	7.89	**1**	1	1	0	77	10	18	19
B	2	3 to 5	22	7	6.19	0	**0**	1	0	21	10	15	19
C	3	6 to 10	30	10	6.95	0	0	**0**	0	30	10	12	20
D	4	11 to 15	37	12	5.09	0	0	0	**0**	37	10	7	20
E	5	16 to 25	144	46	4.93	0	0	0	0	**144**	10	0	20
F	Total		313	100		1	1	2	0	309	10	8	20

Table 91

Treatment transition matrix for 3.5-in. HMA overlay of flexible local roads based on the rut depth data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in)							
									0.17	0.04			
A	1	0 to 2	90	30	0.08	**0**	0	0	0	90	10	19	20
B	2	3 to 5	15	5	0.12	0	**0**	0	0	15	10	16	20
C	3	6 to 10	12	4	0.06	0	0	**0**	0	12	10	12	20
D	4	11 to 15	40	14	0.06	0	0	0	**0**	40	10	7	20
E	5	16 to 25	139	47	0.06	0	0	0	1	**138**	10	0	20
F	Total		296	100		0	0	0	1	295	10	8	20

Table 92

Treatment transition matrix for 3.5-in. HMA overlay of flexible local roads based on the DOTD deduct points for rut depth

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
									13.53	1.70			
A	1	0 to 2	13	25	4.89	**0**	0	0	0	13	10	19	20
B	2	3 to 5	3	6	8.89	0	**0**	0	0	3	10	16	20
C	3	6 to 10	2	4	1.52	0	0	**0**	0	2	10	12	20
D	4	11 to 15	1	2	2.99	0	0	0	**0**	1	10	7	20
E	5	16 to 25	33	63	9.05	0	0	0	1	**32**	9	0	20
F	Total		52	100		0	0	0	1	51	10	6	20

Table 93
Existing and calibrated Louisiana deduct points trigger values for rut depths in flexible and composite collector and local roads

Pavement distress and/or condition							
Pavement Type	Status of trigger values	Distress/condition type	Treatment type for flexible and composite Interstate				
			Collector and local				
			9	10(12)	11(14)	12(15)	13
Flexible	Current trigger values	Rut depth (in)	≤0.563	>0.25 to ≤0.563	>.563	>0.563	-
		Indices	≥65	≥65 to<90	<65	<65	-
	Calibrated trigger values	Rut depth (in)	≤0.35	>0.25 to ≤0.5	>0.375 to <0.625	>0.5 to ≤0.625	-
		Indices^1	≥82	≥70 to <90	>60 to <80	≥60to <70	-
		Indices^2	≥82	≥70 to <90	>60 to <80	≥60 to <70	-
Composite	Current trigger values	Rut depth (in)	-	>0.25 to ≤0.563	>.563	>0.563	-
		Indices	-	≥65 to<90	<65	-	-
	Calibrated trigger values	Rut depth (in)	-	>0.25 to ≤0.5	>0.375 to <0.625	>0.5 to ≤0.625	-
		Indices^1	-	≥70 to <90	>60 to <80	≥60to <70	-
		Indices^2	-	≥70 to <90	>60 to <80	≥60 to <70	-

Treatment	Treatment Type and Description
9	Polymer Surface Treatment on Collector
10(12)	Microsurfacing on Collector
11(14)	Thin Overlay on Collector (2" Overlay; 0-100 Square Yards Patching)
12(15)	Medium Overlay on Collector (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-500 Square Yards Patching)
13	In Place Stabilization on Collector (In-Place Stabilization & 3" A.C.)
Indices^1 equals Based on the existing DOTD deduct points	
Indices^2 equals Based on the recommended deduct points. *Values in parentheses represent composite treatments	

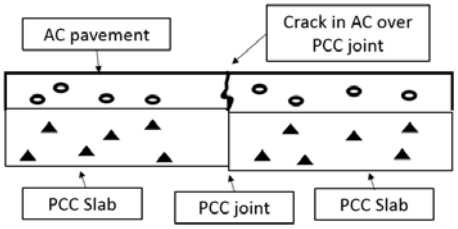
Calibration of the IRI Trigger Values for Flexible and Composite Pavements

Unlike the calibration of the rut depth trigger values, the calibration of the IRI trigger values are based on four criteria:

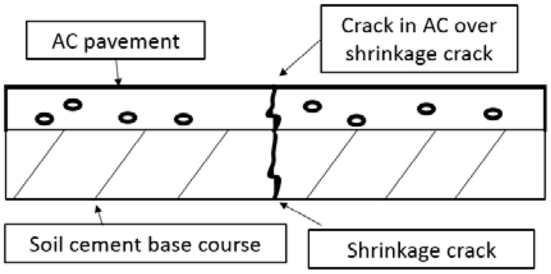
- The state -of-the-practice in the state of Louisiana.
- The measured IRI values before and after treatments.
- The benefits of the various treatments as defined earlier in this chapter.
- Road class

Although the existing DOTD IRI trigger values for flexible and composite pavements are slightly different, the calibrated values are the same. The main reason is that the DOTD does not have sufficient data for the calibration of the trigger values in composite pavements. Please note that the calibrated IRI trigger values for composite pavements are based on the fact that both flexible and composite pavements are HMA surfaced pavements. Further, the differences in the factors affecting IRI in composite and flexible pavements are:

- In composite pavements, reflective cracks generally develop over time as presented in Figure 112a. The width of the crack varies and can lead to spalling in the AC [72][92]. Occasionally, faulting may occur in the AC mirroring the faulting in the underlying PCC. Both the cracking and faulting if present, contribute to decreasing ride quality.



a) Reflective transverse crack in composite pavements



b) Reflective crack in flexible pavements

Figure 112
Reflective cracks in composite pavement and transverse cracks in flexible pavements

- In flexible pavements, the transverse cracks are typically caused by shrinkage cracks in the underlying soil cement base course as presented in Figure 112b. These cracks can vary in width and unlike with composite pavements, neither spalling or faulting generally occur.

Flexible and Composite Pavements for Interstate. Unfortunately, the DOTD database for 2-in. and 3.5-in. HMA overlay treatments of flexible and composite interstate pavements does not contain statistically significant data to be used in the calibration of the IRI trigger values. For 2- and 3.5-in. HMA overlay, the database contains, respectively, data for only 0.6 mile and 0.7 mile as provided in the treatment transition matrices of Table 94 and Table 95. Therefore, the calibration of the IRI trigger values was accomplished using data from the states of Washington, Colorado, and Michigan. The findings from the three states are enumerated below:

1. The maximum acceptable IRI varies from one State Highway Agency to the next with an average of 160 inch/mile.
2. Microsurfacing is rarely used to fix pavement roughness with an average microsurfacing life of less than 3 years.
3. On average 2-in. overlay and/or 2-in. mill and fill treatment is used for moderately rough road where the IRI ranges up to 125 inch/mile.
4. On average 3.5-in. HMA overlay and/or 2-in. mill and 3.5-in. HMA overlay treatment is used for flexible and composite interstate roughness of more than 125 inch/mile. The 3.5-in. HMA overlay is constructed on 2 courses to provide smoother ride.

The existing DOTD and the calibrated trigger values are listed in Table 96. It should be noted that the recommended IRI deduct points are the same as those used by the DOTD.

Flexible and Composite Pavements for Arterial Roads. The DOTD database contains a statistically significant data for the calibration of the IRI trigger values for flexible and composite arterial pavements. Indeed, the available DOTD data parallel the available data from the states of Washington, Colorado, and Michigan. Nevertheless, Table 97 and Table 98 provide the pavement transition matrices for 2-in. overlay based on the actual IRI data and on the IRI deduct points. It can be seen that data for more than 80 of 0.1 mile pavement segments (or 8 miles of road) are housed in the matrices.

Table 94

Treatment transition matrix for 2-in. HMA overlay of flexible and composite Interstates based on the actual IRI data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
									2	8			
A	1	0 to 2	4	67	11	**0**	0	0	1	3	10	17	18
B	2	3 to 5	1	17	15	0	**0**	0	0	1	10	16	20
C	3	6 to 10	0	0		0	0	**0**	0	0			
D	4	11 to 15	0	0		0	0	0	**0**	0			
E	5	16 to 25	1	17	1	0	0	0	0	**1**	10	0	20
F	Total		6	100		0	0	0	1	5	10	14	19

Table 95

Treatment transition matrix for 3.5-in. HMA overlay of flexible and composite Interstates based on the actual IRI data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
									10	18			
A	1	0 to 2	1	14	32	**0**	0	0	0	1	10	19	20
B	2	3 to 5	0	0		0	**0**	0	0	0			
C	3	6 to 10	0	0		0	0	**0**	0	0			
D	4	11 to 15	6	86	27	0	0	0	**1**	5	10	6	19
E	5	16 to 25	0	0		0	0	0	0	**0**			
F	Total		7	100		0	0	0	1	6	10	8	19

Table 96
Existing Louisiana trigger values for IRI in flexible and composite Interstate pavements and the calibrated trigger values for flexible and composite Interstate pavements

Pavement distress and/or condition						
Pavement Type	Status of trigger values	Distress/condition type	Treatment type for flexible and composite Interstate			
			1(1)	2(2)	3(3)	4(4)
Flexible	Current trigger values	IRI (inch/mile)	≤125	>100 to ≤125	>125	-
		Indices	≥85	≥85 to <90	<85	-
	Calibrated trigger values	IRI (inch/mile)	N/A	>100 to ≤125	>125	N/A
		Indices	N/A	≥85 to <90	<85	N/A
Composite	Current trigger values	IRI (inch/mile)	≤100	>100 to ≤125	>125	-
		Indices	≥90	≥85 to <90	<85	-
	Calibrated trigger values	IRI (inch/mile)	N/A	>100 to ≤125	>125	N/A
		Indices	N/A	≥85 to <90	<85	N/A

Treatment	Treatment Type and Description
1(1)	Microsurfacing on Interstate
2(2)	Thin Overlay on Interstate (Cold Plane 2", put 2" back; 0-100 Square Yards Patching)
3(3)	Medium Overlay on Interstate (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-300 Square Yards Patching)
4(4)	Structural Overlay on Interstate (7" Overlay; 700 Square Yards Patching)

*Values in parentheses represent composite treatments

Table 97

Treatment transition matrix for 2-in. HMA overlay of flexible and composite arterial roads based on the IRI data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
								2	16	6			
A	1	0 to 2	41	50	31	**0**	0	0	4	37	10	18	19
B	2	3 to 5	6	7	19	0	**0**	0	1	5	10	15	19
C	3	6 to 10	4	5	33	0	0	**0**	0	4	10	12	20
D	4	11 to 15	3	4	11	0	0	0	**0**	3	9	7	20
E	5	16 to 25	28	34	13	0	0	1	0	**27**	9	0	20
F	Total		82	100		0	0	1	5	76	10	11	19

Table 98

Treatment transition matrix for 2-in. HMA overlay of flexible and composite arterial roads based on the DOTD deduct points for IRI

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in/mi)							
			Number	Percent		0	1	2	1	1			
A	1	0 to 2	57	69	6	**1**	0	13	23	20	10	13	14
B	2	3 to 5	7	8	3	0	**0**	5	0	2	9	7	11
C	3	6 to 10	6	7	2	0	0	**0**	4	2	9	7	15
D	4	11 to 15	3	4	5	0	0	0	**1**	2	10	5	18
E	5	16 to 25	10	12	2	0	1	2	2	**5**	8	-5	15
F	Total		83	100		1	1	20	30	31	9	10	14

The data in Table 97 and Table 98 indicate that:

1. The before treatment remaining service life based on the IRI data (Table 97) and on the deduct points (Table 98) varies from zero to 25 years. This variation corresponds to before treatment IRI variation from 200 to less than 50 inch/mile. Indeed, considering the data in Table 20, the before treatment IRI of 50% of the 82 0.1 mile long pavement segments have had IRI more than 190 inch/mile whereas the IRI of 34% is less than 55 inch/mile. These percentages are 69 and 12 based on the deduct points data in Table 98.
2. The after treatment data listed in Table 98 indicate that the after treatment IRI of only 20 of the 57 0.1 mile long pavement segments (or about 33%) was restored to less than 55 inch/mile.

The first observation implies that the ride quality along the pavement projects before treatment was highly variable. The second observation implies that the 2-in. HMA overlay was applied a little too late for some of the 0.1 mile pavement segment.

Similar observations can be made from the data listed in the treatment transition matrices of Table 99 and Table 100. Once again, the implication is that when the before treatment IRI is higher than about 175 inch/mile, the full benefits of the treatment are not realized. This is true if the overlay is applied on one course (2 in. thick) or two courses (3.5 in. thick). Based on these observations, the trigger values for IRI were calibrated. The calibrated values are listed in Table 101.

Finally, the DOTD database does not have sufficient data to calibrate the trigger values for microsurfacing and structural overlay treatments. However, the data from other State Highway Agencies indicate that microsurfacing is not a good option to improve the ride quality. No data are available for structural overlay of 4 in. or more to calibrate the trigger value based on actual data.

Flexible and Composite Pavements for Collector and Local Roads. The DOTD database contains a statistically significant data for the calibration of the IRI trigger values for flexible collector roads that received 2-in. and 3.5-in. HMA overlays. Sufficient data are also available for the calibration of the IRI trigger values for 3.5-in. HMA overlay on flexible local roads. The database does not contain sufficient data for the 2.0-in. overlay of flexible local roads. Table 102 and Table 103 list the treatment transition matrices for flexible arterial roads subjected to 2-in. HMA overlay. Table 102 is based on the IRI data while Table 103 is based on the DOTD deduct points. The data listed in the after treatment section of the two matrices indicate that the HMA overlay was not effective when it is applied to pavement segments having IRI values higher than 175 inch/mile or higher deduct points. For example, in Table 102, only 101 pavement segments (10.1 miles) of the 155 segments were restored to IRI value of about 65 inch/mile. The after treatment IRI of the other 54 segments varied from

90 to about 200 inch/mile. Likewise, the after treatment data in Table 103, indicate that the deduct points of only 70 of 179 pavement segments was zero. The deduct points of the other 109 segments varied from 10 to more than 30.

Similar observations can be made from the data listed in the treatment transition matrices of Table 104 and Table 105 for 3.5-in. HMA overlay of flexible arterial roads and in Table 106 and Table 107 for 3.5-in. HMA overlay on local roads.

The above observations indicate that the benefits from the treatment decrease substantially when the treatment is applied to pavement segments having high IRI or high deduct points. Therefore, the calibration of the IRI trigger values is based on maximizing the benefits of the treatment. The existing IRI trigger values and the calibrated ones are listed in Table 108.

Table 99

Treatment transition matrix for 3.5-in. HMA overlay of flexible and composite arterial roads based on the IRI data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in/mi)							
							57	12	6	4			
A	1	0 to 2	189	64	30	**0**	3	9	17	160	10	18	19
B	2	3 to 5	34	12	18	0	**0**	5	5	24	10	13	17
C	3	6 to 10	18	6	16	0	0	**1**	4	13	10	10	18
D	4	11 to 15	17	6	12	0	0	0	**1**	16	10	7	20
E	5	16 to 25	37	13	18	0	0	4	3	**30**	9	-2	18
F	Total		295	100		0	3	19	30	243	10	14	18

Table 100

Treatment transition matrix for 3.5-in. HMA overlay of flexible and composite arterial roads based on the DOTD deduct points for IRI

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
							14	2	1	1			
A	1	0 to 2	206	68	6	**0**	8	67	33	98	9	13	14
B	2	3 to 5	25	8	4	0	**0**	14	3	8	8	8	12
C	3	6 to 10	17	6	4	0	0	**11**	2	4	8	3	11
D	4	11 to 15	24	8	4	0	1	8	**2**	13	8	2	15
E	5	16 to 25	33	11	4	0	1	17	5	**10**	8	-8	12
F	Total		305	100		0	10	117	45	133	9	9	14

Table 101

Existing Louisiana trigger values for IRI in flexible and composite arterial roads for the listed treatment types and the calibrated trigger values for flexible and composite pavements on arterial roads

Pavement distress and/or condition						
Pavement Type	Status of trigger values	Distress/condition type	Treatment type			
			Arterial 2, 70 mph			
			5(5)	6(7)	7(8)	8(10)
Flexible	Current trigger values	IRI (inch/mile)	≤150	>100 to ≤200	>200	-
		Indices	≥80	≥70 to <90	<70	-
	Calibrated trigger values	IRI (inch/mile)	N/A	>100 to ≤150	>150 to ≤175	N/A
		Indices	N/A	≥80 to <90	≥75 to <80	N/A
Composite	Current trigger values	IRI (inch/mile)	≤150	>100 to ≤200	>200	-
		Indices	≥80	≥70 to <90	<70	-
	Calibrated trigger values	IRI (inch/mile)	N/A	>100 to ≤150	>150 to ≤175	N/A
		Indices	N/A	≥80 to <90	≥75 to <80	N/A

Treatment	Treatment Type and Description
5(5)	Microsurfacing on Arterial
6(7)	Thin Overlay on Arterial (Cold Plane 2", put 2" back; 0-100 Square Yards Patching)
7(8)	Medium Overlay on Arterial (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-300 Square Yards Patching)
8(10)	Structural Overlay on Arterial (5.5" Overlay; 700 Square Yards Patching)

*Values in parentheses represent composite treatments

Table 102

Treatment transition matrix for 2-in. HMA overlay of flexible collector roads based on the IRI data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in/mi)							
			Number	Percent		24	16	15	9	4			
A	1	0 to 2	155	41	17	**2**	2	13	37	101	10	16	17
B	2	3 to 5	24	6	14	0	**0**	0	2	22	10	15	19
C	3	6 to 10	29	8	12	0	0	**3**	4	22	9	10	18
D	4	11 to 15	120	32	8	0	0	6	**8**	106	9	6	19
E	5	16 to 25	48	13	9	0	0	3	2	**43**	10	-1	19
F	Total		376	100		2	2	25	53	294	10	10	18

Table 103
Treatment transition matrix for 2-in. HMA overlay of flexible collector roads based on the DOTD deduct points for IRI

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
						5	5	3	1	1			
A	1	0 to 2	179	48	4	**2**	5	64	38	70	9	13	14
B	2	3 to 5	22	6	3	0	**1**	6	6	9	9	10	14
C	3	6 to 10	33	9	2	0	1	**4**	6	22	10	9	17
D	4	11 to 15	101	27	2	0	4	29	**29**	39	8	1	14
E	5	16 to 25	35	9	2	0	1	4	11	**19**	9	-4	16
F	Total		370	100		2	12	107	90	159	9	7	14

Table 104
Treatment transition matrix for 3.5-in. HMA overlay of flexible collector roads based on the IRI data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in/mi)							
			Number	Percent		1	71	20	11	4			
A	1	0 to 2	728	56	28	**2**	8	48	73	597	10	17	18
B	2	3 to 5	104	8	16	0	**0**	5	3	96	10	15	19
C	3	6 to 10	122	9	13	0	0	**5**	6	111	10	11	19
D	4	11 to 15	128	10	11	0	1	2	**4**	121	10	6	19
E	5	16 to 25	216	17	8	0	0	4	3	**209**	10	0	20
F	Total		1298	100		2	9	64	89	1134	10	13	19

Table 105

Treatment transition matrix for 3.5-in. HMA overlay of flexible collector roads based on the DOTD Deduct points for IRI

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
							13	2	1	1			
A	1	0 to 2	459	37	7	**0**	10	111	77	261	9	15	16
B	2	3 to 5	124	10	5	0	**1**	29	30	64	9	11	15
C	3	6 to 10	155	13	3	0	4	**33**	33	85	9	8	16
D	4	11 to 15	171	14	3	0	2	36	**29**	104	9	3	16
E	5	16 to 25	325	26	2	0	0	46	80	**199**	9	-3	17
F	Total		1234	100		0	17	255	249	713	9	7	16

Table 106

Treatment transition matrix for 3.5-in. HMA overlay of flexible local roads based on the IRI data

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in/mi)							
						7	16	15	6	4			
A	1	0 to 2	252	89	19	**3**	0	12	13	224	10	18	19
B	2	3 to 5	13	5	22	0	**0**	1	1	11	9	15	19
C	3	6 to 10	6	2	13	0	1	**1**	0	4	8	7	15
D	4	11 to 15	1	0	4	0	0	1	**0**	0	2	-5	8
E	5	16 to 25	11	4	11	0	1	0	1	**9**	9	-2	18
F	Total		283	100		3	2	15	15	248	10	17	19

Table 107

Treatment transition matrix for 3.5-in. HMA overlay of flexible local roads based on the DOTD deduct points for IRI

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the number of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in/mi)							
			Number	Percent		2		3	1	1			
A	1	0 to 2	202	74	4	**1**	0	47	34	120	10	15	16
B	2	3 to 5	13	5	3	0	**0**	4	1	8	9	12	16
C	3	6 to 10	16	6	3	0	0	**0**	2	14	9	11	19
D	4	11 to 15	17	6	3	1	0	1	**1**	14	8	5	18
E	5	16 to 25	25	9	3	0	0	6	1	**18**	9	-3	17
F	Total		273	100		2	0	58	39	174	9	12	16

Table 108
Existing and calibrated IRI trigger values for flexible and composite collector and local roads for the listed treatment types

Pavement distress and/or condition							
Pavement Type	Status of trigger values	Distress or condition type	Treatment type				
			Collector and local				
			9	10 (12)	11 (14)	12 (15)	13
Flexible	Current trigger values	IRI (inch/mile)	≤150	≤150	≤225 >150	≤275 >225	>275
		Indices	≥80	≥80	≥65 to <80	≥55 to <65	<55
	Calibrated trigger values	IRI (inch/mile)	N/A	>100 to ≤125	>125 to ≤150	>150 to ≤175	N/A
		Indices	N/A	≥85 to <90	≥85 to <90	>75 to <80	N/A
Composite	Current trigger values	IRI (inch/mile)	N/A	≤150	≤225 >150	<225	N/A
		Indices	N/A	≥80	≥65 to <80	>65	N/A
	Calibrated trigger values	IRI (inch/mile)	N/A	>100 to ≤125	>125 to ≤150	>150 to ≤175	N/A
		Indices	N/A	≥85 to <90	≥85 to <90	>75 to <80	N/A

Treatment	Treatment Type and Description
9	Polymer Surface Treatment on Collector
10 (12)	Microsurfacing on Collector
11 (14)	Thin Overlay on Collector (2" Overlay; 0-100 Square Yards Patching)
12 (15)	Medium Overlay on Collector (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-500 Square Yards Patching)
13	In Place Stabilization on Collector (In-Place Stabilization & 3" A.C.)

*Values in parentheses represent composite treatments

Calibration of Trigger values for Cracking in Flexible and Composite Pavements

The calibration of the DOTD trigger values for pavement cracking is based on the following criteria:

1. The state -of-the-practice in the state of Louisiana, including the existing trigger values and the remaining service life based on the actual measured data and on the deduct points.
2. The measured time dependent cracking data before and after treatments.
3. The historical benefits of the treatments, as defined earlier in this chapter.
4. Road class and pavement type.
5. Type of pavement fix.
6. Cracking type (alligator, transverse, longitudinal, and random).

For each road class, pavement condition or distress type, and for each fix type, two tier analyses were conducted when possible. One tear is based on the actual measured data and the corresponding threshold value presented in previous section and the other is based on the DOTD deduct points and the associated trigger values. For each tear of analyses and for each 0.1 mile long pavement segment, two remaining service life values were calculated. One value was based on the before treatment data and the other on the after treatment data. As stated earlier, the data for each 0.1 mile long pavement segment along each pavement project were first subjected to two acceptance criteria. In certain scenarios, the number of 0.1 mile long pavement segments that were available for the analyses was statistically insignificant to arrive at sound decisions. The reasons were identified were:

1. The DOTD database did not contain sufficient number of pavement projects or sufficient cumulative lengths of projects.
2. The DOTD database has sufficient number of pavement projects but the percent of the projects that failed the acceptance criteria was high.

Results of the analyses are presented and discussed below in several sections. The materials and the sections are organized by pavement type, road class, and then further by pavement cracking type.

Flexible Pavements for Interstate Roads. Unfortunately, the DOTD database does not contain statistically sufficient data to conduct the full analyses of all cracking types. The term statistically sufficient implies more than 3 miles or 30 of 0.1 mile long pavement segments. Results of the analyses of the available performance data of flexible pavement projects along the Interstates are presented and discussed in this section.

1. Alligator Cracking

Currently for the Interstates, DOTD specifies trigger values based on the distress index/deduct points for the four pavement condition or distress types and the four fixes listed in Table 109. Results of the analyses for IRI and rut depths are presented and discussed in earlier sections of this chapter. This subsection presents and discusses the results of the analyses of the alligator cracking data for Interstates.

At the outset, it should be noted that the DOTD database did not have statistically significant data to calibrate the trigger values for microsurfacing and structural overlay. The database contained very limited data for 2-in. and 3.5-in. overlay treatments. Results of the analyses of the latter data are presented and discussed below.

Table 110 and Table 111 list the treatment transition matrices for 2 and 3.5-in. HMA overlay of flexible pavements along the Interstates. The two tables are based on the measured alligator cracking data and alligator cracking threshold of 1267 ft^2. This represents 3 ft. wide alligator cracks in each wheel path along 211 ft. or 40% of a 0.1 mile long pavement segment. The DOTD thresholds are less than 330 ft^2 or less than 10 deduct points (see Table 109). Unfortunately, when the DOTD deduct points were used, an insufficient number of 0.1 mile long pavement segments passed the two acceptance criteria. Hence, the deduct point results are not included herein.

The before treatment data in Table 109 indicate that a total of 43 0.1 mile long pavement segments (4.3 miles) were subjected to 2-in. HMA overlay. The alligator cracking area of each of 34 segments (84% of the projects) was close to the threshold value of 1267 ft^2 (RSL between 0.0 and 2 years). Few segments were in RSL brackets 2 and 3. After the application of 2-in. HMA overlay treatment, 94% of the 34 segments were moved to RSL bracket 5. While 100% of the segments that were in bracket 2 before treatment moved to bracket 5 after treatment. This implies that the 2-in. HMA overlay treatment is more effective when the existing before treatment condition is RSL bracket 2, which corresponds to about 500 ft^2 of alligator cracks. However, given the limited number of data points available in the DOTD database, the recommended threshold value is the same as the current DOTD value of less than 330 ft^2.

Similarly, Table 110 shows that the data for only 51 of the 0.1 mile long pavement segments (5.1 miles) are available for the analysis of the pavement performance before and after the application of 3.5-in. HMA overlay. The before treatment data in the table indicate that 10 segments were in poor condition (RSL between 0.0 and 2 years), 2 segments in fair condition, 8 in good condition, and 31 in very good condition. After treatment, the conditions of the 10 segments improved such that the conditions of 4 segments or 40% became excellent and 6 segments or 60% very good, whereas the two segments that were in fair condition moved to excellent condition. Once again, this very limited amount of data suggest that the maximum benefits belong to those segments that were in RSL brackets 1 and 2. These correspond to a threshold value for alligator cracking between 500 and 1267 ft^2.

Given that the trigger value for the 2-in. overlay is 330 ft^2, the recommended trigger value range for alligator cracking along Interstates and for 3.5-in. HMA overlay treatment is 330 to 1267 ft^2. Because of the size of the data, this recommended range of the trigger value is preliminary in nature. The range should be calibrated again as soon as performance data of more pavement sections subjected to 3.5-in. HMA overlay become available. Although the DOTD database does not have data regarding structural overlay on alligator cracked Interstate pavements, the logical trigger value should be set above the 1267 ft^2 noted above.

Table 109

Existing and calibrated Louisiana trigger values for four distress types in flexible Interstate pavements

Pavement condition/distress	Interstate							
	Treatment type and current DOTD trigger values based on distress and deduct points*				Treatment type and calibrated trigger values based on distress and deduct points*			
	1	2	3	4	1	2	3	4
Alligator cracking (ft^2)	≤82	≤330	>330 to	>2033	≤82	≤330	≥330to≤1267	> 1267
Transverse cracking (ft)	≤50	≤301	>205	-	≤50	≤301	>301	-
Longitudinal cracking (ft)	≤50	≤301	>205	-	≤50	≤528	>528	-
Random cracking (ft)	≤50	≤301	>205	-	≤50	≤301	>301	-
	Deduct values/distress index				Deduct values[1]/distress index			
Alligator cracking	≤2/>98	≤10/≥90	>10 to ≤35/ <91 to ≥65	>35/<65	≤2/>98	≤10/≥90	≥10 to ≤26/ ≤90 to ≥74	>26/<74
Transverse cracking (ft)	≤2/>98	≤15/≥85	>10/<90	-	≤2/>98	≤15/≥85	≤15/≥85	-
Longitudinal cracking (ft)	≤2/>98	≤15/≥85	>10/<90	-	≤2/>98	≤17/≥83	≤17/≥83	-
Random cracking	≤2/>98	≤15/≥85	>10/<90	-	≤2/>98	≤15/≥85	≤15/≥85	-
					Deduct values[2]/distress index			
Alligator cracking					≤2/>98	≤12/≥88	≥12 to ≤31/ <88 to >69	>31/<69
Transverse cracking (ft)					≤2/>98	≤19/≥81	≤19/≥81	-
Longitudinal cracking (ft)					≤2/>98	≤29/≥71	≤29/≥71	-
Random cracking					≤2/>98	≤19/≥81	≤19/≥81	-
[1] Based on the existing deduct values; [2] Based on the recommended deduct values (see Chapter 1)								

Treatment type	Description
1	Microsurfacing on Interstate
2	Thin overlay on interstate (cold plane 2", put 2" back; 0-100 square yards patching)
3	Medium overlay on interstate (cold plane 2", put 3.5" back or just 3.5" overlay, 100-300 square yards patching)
4	Structural overlay on interstate (7" overlay; 700 square yards patching)

*Value of trigger corresponds to high deducts.

Table 110

Treatment transition matrix for 2-in. HMA overlay on flexible Interstate pavement sections, RSL, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
									22	1			
A	1	0 to 2	36	84	257	**0**	0	0	6	94	10	19	20
B	2	3 to 5	5	12	7	0	**0**	0	0	100	10	16	20
C	3	6 to 10	2	5	3	0	0	**0**	50	50	9	9	17
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		43	100		0	0	0	7	93	10	18	20

Table 111

Treatment transition matrix for 3.5-in. HMA overlay on flexible Interstate pavement sections, RSL, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
								1	1	1			
A	1	0 to 2	10	20	757	**0**	0	0	60	40	10	15	16
B	2	3 to 5	2	4	48	0	**0**	0	0	100	10	16	20
C	3	6 to 10	8	16	1319	0	0	**13**	88	0	8	4	12
D	4	11 to 15	31	61	1262	0	0	6	**94**	0	9	0	13
E	5	16 to 25	0	0									
F	Total		51	100		0	0	6	82	12	9	4	14

The calibrated trigger values for various treatments based on the extent of alligator cracking on Interstate flexible pavements are listed in Table 109. Two sets of trigger values based on deduct points are also listed in the table. One set (deduct points^1) is based on the existing DOTD deduct points system. The other (deduct points^2) is based on the new deduct points system recommended. Finally, because of lack of data, the trigger values in the shaded cells in Table 109 are the same as those used by the DOTD.

2. Transverse, Longitudinal and Random Cracking

The current DOTD deduct points and trigger values for transverse, longitudinal, and random cracking are the same as shown in Table 109. Once again the DOTD database contained limited pavement performance data regarding the three crack types. The database contains the following data:

1. The before and after treatment pavement performance data relative to transverse cracking for only 3.5 miles (35 of 0.1 mile pavement segments) that were subjected to 2-in. HMA overlay.
2. The before and after treatment pavement performance data relative to longitudinal cracking for only 4.0 miles (40 of 0.1 mile pavement segments) that were subjected to 2-in. HMA overlay.
3. The before and after treatment pavement performance data relative to transverse cracking for only 1.2 miles (12 of 0.1 mile pavement segments) that were subjected to 3.5-in. HMA overlay.
4. The before and after treatment pavement performance data relative to transverse and longitudinal cracking for only 1.2 miles (12 of 0.1 mile pavement segments) that were subjected to 3.5-in. HMA overlay. Statistically, the sample size is insignificant to arrive at sound decisions.
5. No random cracking data for either the 2.0 or the 3.5-in. HMA overlays.
6. No statistically significant pavement performance data based on deduct points passes the two acceptance criteria.

For the 2-in. HMA overlay treatment, Table 112 and Table 113 provide lists of the treatment transition matrices data based on transverse and longitudinal cracking, respectively. Examination of the data in Table 112 indicates that the 2-in. HMA overlay treatment is most effective when applied to pavement segments whose before treatment conditions correspond to RSL bracket 2. The treatment caused the largest service life extension of 14 years. Since the data in the table are based on a threshold value of 528 ft. of transverse cracking, RSL bracket 2 before treatment corresponds to about 320 ft. of transverse cracking. This is very much the same as the existing DOTD trigger value of < 301ft. Hence, the recommended trigger value for transverse cracking and 2-in. overlay treatment is less than or equal to 301 linear ft. of cracking.

The data in Table 113, on the other hand, indicates that the effectiveness of the 2-in. HMA overlay treatment is the highest when applied to pavement segments having before treatment conditions correspond to RSL bracket 1. The treatment caused the largest service life extension of 19 years. Since the data in the table are based on a longitudinal cracking threshold value of 528 ft., RSL bracket 1 corresponds to 528 linear ft. of longitudinal cracks. This is slightly higher than the existing DOTD trigger value of < 301ft.

Nevertheless, the recommended trigger value for longitudinal cracking and 2-in. overlay treatment is less than or equal to 528 linear ft. of cracking.

Since random cracking is the sum of transverse and longitudinal cracks, the recommended trigger values based on distress and on deduct points are the lowest of the trigger values of the transverse and longitudinal cracks.

The calibrated trigger values for various treatments based on the extent of distress (transverse, longitudinal and random cracking) on Interstate flexible pavements are listed in Table 109. Two sets of trigger values based on deduct points are also listed in the table. One set (deduct points^1) is based on the existing DOTD deduct points system. The other (deduct points^2) is based on the new deduct points system as recommended. Finally, because of lack of data, the trigger values in the shaded cells in Table 109 are the same as those used by the DOTD.

Table 112

Treatment transition matrix for 2-in. HMA overlay on flexible Interstate pavement sections, RSL, transverse cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
								113	5	1			
A	1	0 to 2	7	20	313	**0**	0	57	14	29	9	11	12
B	2	3 to 5	12	34	40	0	**0**	17	0	83	9	14	18
C	3	6 to 10	6	17	5	0	0	**0**	0	100	10	12	20
D	4	11 to 15	6	17	5	0	0	0	**0**	100	8	7	20
E	5	16 to 25	4	11	3	0	0	0	0	**100**	7	0	20
F	Total		35	100		0	0	17	3	80	9	10	18

Table 113
Treatment transition matrix for 2-in. HMA overlay on flexible Interstate pavement sections, RSL, longitudinal cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
									42	1			
A	1	0 to 2	27	68	74	**0**	0	0	0	100	10	19	20
B	2	3 to 5	4	10	12	0	**0**	0	0	100	10	16	20
C	3	6 to 10	4	10	5	0	0	**0**	25	75	9	10	18
D	4	11 to 15	4	10	54	0	0	0	**0**	100	9	7	20
E	5	16 to 25	1	3	98	0	0	0	0	**100**	9	0	20
F	Total		40	100		0	0	0	3	98	10	16	20

Flexible Pavements for Arterial Roads. The analyses of arterial roads were conducted in two tears; based on RSL values that were calculated using the deduct points and based on RSL values that were calculated using the actual distress data. In general, the number of pavement segments that passed the two acceptance criteria was much higher for the latter tear. The main reason is that the deduct points are assigned based on the distress severity levels, which are not consistent from one year to the next as stated before. Nevertheless, the DOTD database does not contain statistically sufficient data to conduct the full analyses of all cracking and treatment types. Once again, the term "statistically sufficient" implies more than 3 miles or 30 of 0.1 mile long pavement segments. Despite an exhaustive search of the DOTD database, only a few short pavement projects (few 0.1 mile long pavement segments) were located for certain distress and treatment types. For the following distress and treatment types, the numbers of 0.1 mile long pavement segments where their time dependent deduct points and distress data passed the two acceptance criteria are listed below.

1. For transverse and longitudinal cracking along arterial roads that received 2-in. HMA overlay treatment, the numbers of 0.1 mile long pavement segments where their time dependent deduct points passed the two acceptance criteria are 11 and 2, respectively.
2. For transverse and longitudinal cracking along arterial roads that received 2-in. HMA overlay treatment, the numbers of 0.1 mile long pavement segments where their time dependent distress data passed the two acceptance criteria are 26 and 14, respectively.
3. For transverse and longitudinal cracking along arterial roads that received 3.5-in. HMA overlay treatment, the numbers of 0.1 mile long pavement segments where their time dependent deduct points passed the two acceptance criteria are 14 and 18, respectively.

The same search of the DOTD database yielded good numbers of pavement projects for the distress and treatment types listed below.

1. For alligator cracking along arterial roads that received 2-in. HMA overlay treatment, the time dependent deduct points of 51 of 0.1 mile long pavement segments passed the two acceptance criteria. Whereas the time dependent alligator cracking data of 115 of 0.1 mile pavement segments passed the two acceptance criteria.
2. For alligator cracking along arterial roads that received 3.5-in. HMA overlay treatment, the time dependent deduct points of 56 of 0.1 mile long pavement segments passed the two acceptance criteria. Whereas the time dependent alligator cracking data of 374 of 0.1 mile pavement segments passed the two acceptance criteria.

3. For transverse and longitudinal cracking along arterial roads that received 3.5-in. HMA overlay treatment, the time dependent transverse and longitudinal cracking data of 172 and 140 of 0.1 mile pavement segments passed the two acceptance criteria, respectively.

The time dependent deduct points and distress data that passed the two acceptance criteria, were subjected to analyses. Results of the analyses of the available performance data of flexible pavement projects along arterial roads are presented and discussed below.

1. Alligator Cracking

Currently, the DOTD specify trigger values based on the distress index/deduct points for the four pavement condition or distress types and the four fixes for arterial roads listed in Table 114. Since no pavement performance data were found for Polymer Surface Treatment, it was not included in the table. Results of the analyses for IRI and rut depths are presented and discussed in earlier sections of this chapter. This subsection presents and discusses the results of the analyses of the alligator cracking data for arterial roads.

At the outset, it should be noted that the DOTD database did not have statistically significant data to calibrate the trigger values for microsurfacing and structural overlay. The database contained very limited data for 2-in. and 3.5-in. overlay treatments. Results of the analyses of the latter data are presented and discussed below.

Table 115 and Table 116 list the treatment transition matrices for 2-in. HMA overlay of flexible pavements along arterial roads based on the time dependent deduct points and the actual alligator cracking data, respectively. Once again it can be seen from the two tables that time dependent distress data of 115 of 0.1 mile long pavement segment passed the two acceptance criteria while the deduct points data of only 51 segments passed the (Table 115). As stated earlier, this is mainly due to the high artificial variability induced in the data while adding the deduct points based on the weight factors between the three severity levels. Nevertheless, the remaining service life values listed in the before and after treatment sections of Table 115 are based on deduct points trigger value of 15 points. Whereas, the remaining service life values listed in the before and after treatment sections of Table 116 are based on alligator cracked area of 1267 ft^2.

The after treatment data listed in Table 115 indicate that 59% of the 51 segments that were in poor conditions (RSL bracket 1) before treatment transferred to excellent condition (RSL bracket 5) after treatment. Further, 18% transferred to each of RSL brackets 3 and 4 and 6% to RSL bracket 2. This data suggest that the 2-in. HMA overlay treatment was not as effective as it could possibly be. Since the before treatment conditions of all pavement segments were in RSL bracket 1, no decision can be made regarding the calibration of the trigger value.

The scenario is much different for the data listed in Table 116. First, the time dependent alligator cracking data of 115 pavement segments were accepted for analysis. Second, the before treatment conditions of the 115 pavement segments were distributed as follows: 72 segments were in poor conditions (RSL bracket 1), 14 in fair (RSL bracket 2), 12 in good (RSL bracket 3), 2 in very good (RSL bracket 4, and 15 in excellent conditions (RSL bracket 5).

The data in the after treatment section of the matrix indicate that the service life of the majority (more than 90 segments) of the 115 segments improved by as few as 3 years and by as much as 18 years. Fifteen segments experienced losses in their service life and about 7 segments experienced no gain. The bottom line is that the data indicate that the effectiveness of the 2-in. HMA overlay treatment varies relative to two factors; the distribution of the before treatment pavement conditions and construction quality. The first factor indicates that, on average, the service life extension of the 2-in. HMA overlay treatment is about 6 years and that the threshold or trigger value of 1267 ft^2 used in the analysis is high. The data suggest that the effectiveness of the 2-in. HMA overlay treatment is the highest for those pavement segments that were in RSL bracket 2 before treatment. This corresponds to a maximum alligator cracking area of about 500 ft^2. The effects of the second factor, construction quality, is evident from the after treatment data of the 15 pavement segments that were in excellent condition (RSL bracket 5) before treatment. The 15 segments experienced an average loss in their service life of 10 years. Based on the data presented in Table 116, the trigger value for alligator cracking area along flexible arterial roads is 500 ft^2. This corresponds to the existing deduct points of 20 points or a distress index of 80, and to the recommended deduct points (see Chapter 1) of 16. These calibrated trigger values are listed in Table 114.

Table 114

Existing and calibrated Louisiana trigger values for four distress types in flexible arterial pavements

Pavement condition/distress	Arterials							
	Treatment type and current DOTD trigger values based on distress and deduct points*				Treatment type and calibrated trigger values based on distress and deduct points*			
	5	6	7	8	5	6	7	8
Alligator cracking (ft^2)	≤144	>260 to ≤490	>490 to <1200	>1200	≤144	>144 to ≤500	>500 to ≤750	> 750
Transverse cracking (ft)	≤75	>75 to <235	>235	-	≤75	>75 to <450	≥450	-
Longitudinal cracking (ft)	≤75	>75 to <235	>235	-	≤75	>75 to <450	≥450	-
Random cracking (ft)	≤75	>75 to <235	>235	-	≤75	>75 to <450	≥450	-
	Deduct values/distress index				Deduct values[1]/distress index			
Alligator cracking	≤5/≥95	>10 to ≤20/ <90 to ≥80	>20 to ≤40/ <80 to ≥60	>40/<60	≤5/≥95	>5 to ≤20/ <95 to ≥80	>20 to ≤30/ <80 to ≥70	>30/<70
Transverse cracking (ft)	≤5/≥95	>5 to ≤20/ <95 to ≥80	>20/<80	-	≤5/≥95	>5 to<26/ <95 to ≥74	≤26/≥74	-
Longitudinal cracking (ft)	≤5/≥95	>5 to ≤20/ <95 to >80	>20/<80	-	≤5/≥95	>5 to<26/ <95 to >74	≤26/≥74	-
Random cracking	≤5/≥95	>5 to ≤20/ <95 to ≥80	>20/<80	-	≤5/≥95	>5 to<26/ <95 to ≥74	≤26/≥74	-
					Deduct values[2]/distress index			
Alligator cracking					≤7/≥93	>7 to <16/ >93 to >84	>16 to ≤22/ <84 to >78	>22/<78
Transverse cracking (ft)					≤7/≥93	>7 to <26/ <93 to >74	≥26/≤74	-
Longitudinal cracking (ft)					≤7/≥93	>7 to <26/ <93 to >74	≥26/≤74	-
Random cracking					≤7/≥93	>7 to <26/ <93 to >74	≥26/≤74	-

[1] Based on the existing deduct values; [2] Based on the recommended deduct values

Treatment type	Description
5	Microsurfacing on arterials
6	Thin overlay on arterials (cold plane 2", put 2" back; 0-100 square yards patching)
7	Medium overlay on arterials (cold plane 2", put 3.5" back or just 3.5" overlay, 100-300 square yards patching)
8	Structural overlay on arterials (7" overlay; 700 square yards patching)

*Value of trigger corresponds to high deducts.

Table 115

Treatment transition matrix for 2-in. HMA overlay on flexible arterial pavement segments, deduct points, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
							21	25	34	39			
A	1	0 to 2	51	100	19	**0**	6	18	18	59	9	15	16
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		51	100		0	6	18	18	59	9	15	16

Table 116

Treatment transition matrix for 2-in. HMA overlay on flexible arterial pavement sections, RSL, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							2341	287	36	32			
A	1	0 to 2	72	63	931	**0**	4	31	61	4	9	10	11
B	2	3 to 5	14	12	1005	0	**7**	7	86	0	10	6	12
C	3	6 to 10	12	10	871	0	0	**42**	42	17	9	4	12
D	4	11 to 15	2	2	545	0	0	0	**50**	50	10	4	17
E	5	16 to 25	15	13	1127	0	13	27	60	**0**	7	-10	10
F	Total		115	100		0	5	34	56	5	9	6	11

The data listed in the before treatment section of Table 117 indicate that the conditions of 55% of the 56 pavement segments included in the analysis are in poor conditions, 41% in fair and 4% in good condition. The after treatment data in the table indicate that the effectiveness of the 3.5-in. HMA overlay is almost the same for those segments that were in poor and fair conditions before treatment. Hence, the data suggest that the trigger value should be the average of the poor and fair conditions or about 650 ft^2 of alligator cracking.

The data in the before treatment section of Table 118 indicate that the 59% of the 374 pavement segments were in poor conditions, 10% in fair, 11% in good, 9% in very good, and 11% in excellent conditions. The data listed in the after treatment section of the table indicate that the 3.5-in. HMA overlay treatment is slightly more effective for those segments that were in fair conditions than all the other segments. The data also indicate that the average life extension of all segments subjected to 3.5-in. HMA overlay is about 9 years. Since poor conditions correspond to 1267 ft^2 of alligator cracking and fair conditions correspond to about 500 ft^2, a calibrated alligator cracking trigger value of 750 ft^2 (which is the same as the current trigger value used by DOTD) appears to be very reasonable. This correspond to the existing deduct points of 30 points or a distress index of 70 and to the recommended deduct points of 22 points or a distress index of 78. These trigger values are listed in Table 114.

Finally, one important observation was made concerning the pavement conditions before and after treatment for the 2-in. and 3.5-in. HMA overlay treatments. Although the DOTD trigger values for the two treatments on arterial roads are not the same, it appears that the collective conditions of all the projects that the received the 2-in. treatment are more or less the same as those that received the 3.5-in. treatment. To illustrate, consider:

a) The before and after treatment distributions of the 0.1 mile pavement segments in the various RSL brackets listed in Table 116 for the 2-in. HMA overlay treatment.
b) The before and after treatment distributions of the 0.1 mile pavement segments in the various RSL brackets listed in Table 118 for the 3.5-in. HMA overlay treatment.

Table 117

Treatment transition matrix for 3.5-in. HMA overlay on flexible arterial pavement segments, deduct points, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
								13	26	39			
A	1	0 to 2	31	55	31	**0**	0	6	3	90	10	18	19
B	2	3 to 5	23	41	27	0	**0**	4	0	96	9	15	19
C	3	6 to 10	2	4	34	0	0	**0**	50	50	6	9	17
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		56	100		0	0	5	4	91	9	17	19

Table 118

Treatment transition matrix for 3.5-in. HMA overlay on flexible arterial pavement segments, RSL, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							542	53	17	7			
A	1	0 to 2	222	59	1047	**0**	3	23	43	31	9	13	14
B	2	3 to 5	36	10	852	0	**3**	14	44	39	9	11	15
C	3	6 to 10	40	11	762	0	0	**28**	40	33	8	6	14
D	4	11 to 15	34	9	667	0	3	29	**35**	32	8	1	14
E	5	16 to 25	42	11	710	0	2	7	43	**48**	9	-4	16
F	Total		374	100		0	2	22	42	34	9	9	14

The two distributions are depicted in Figure 113. It can be seen from the figure that:

1. For the 2-in. HMA overlay (Table 116), the before treatment distribution of the 11.5 mile projects in the various RSL brackets (open symbols) is almost identical to the distribution of the 37.4 mile projects that received 3.5-in. HMA overlay (Table 118). This indicates that the two sets of projects were not treated at the proper time or deduct points as stated in the DOTD trigger value.
2. For the 2-in. HMA overlay (Table 116), the after treatment percentages of the 11.5-mile projects in RSL brackets 3 and 4 (closed symbols) are higher than the percentages of the 37.4-mile projects that received 3.5-in. HMA overlay (Table 118). Whereas, the percent of the 3.5 in. HMA treated pavement segments in after treatment RSL bracket 5 (excellent conditions) is much higher than that for the 2-in. HMA overlay.
3. Although the before treatment distribution in Table 116 is identical to that listed in Table 118, the benefits of the 2-in. HMA overlay treatment in term of service life extension is 6 years, which about two thirds of the 9 years for the 3.5 HMA overlay treatment.

Similar observations could be made for the 2-in. (Table 123) and 3.5-in. (Table 125) HMA overlay treatments of alligator cracked collector roads. The before and after treatment distributions of the 0.1 mile long pavement segments in the various RSL brackets are shown in Figure 114. It can be seen from the figure that:

1. For the 2-in. HMA overlay (Table 123), the before treatment distribution of the 40.1 mile projects in the various RSL brackets (open symbols) is almost identical to the distribution of the 129.1 mile projects that received 3.5-in. HMA overlay (Table 125). This indicates that the two sets of projects were not treated at the proper time or deduct points as stated in the DOTD trigger value.
2. For the 2-in. HMA overlay (Table 123), the after treatment distribution of the 40.1 mile projects in the five RSL brackets (closed symbols) is also identical to the distribution of the 129.1 mile project after receiving the 3.5-in. HMA overlay.
3. The benefits of the 2-in. HMA overlay treatment in term of service life extension is 5 years (see Table 123), which is the same as the benefits of the 3.5 HMA overlay treatment (see Table 125).

The above observations emphasize the importance of the before treatment conditions and their impact on the treatment benefits. They also emphasize the impacts of construction quality on the treatment benefit.

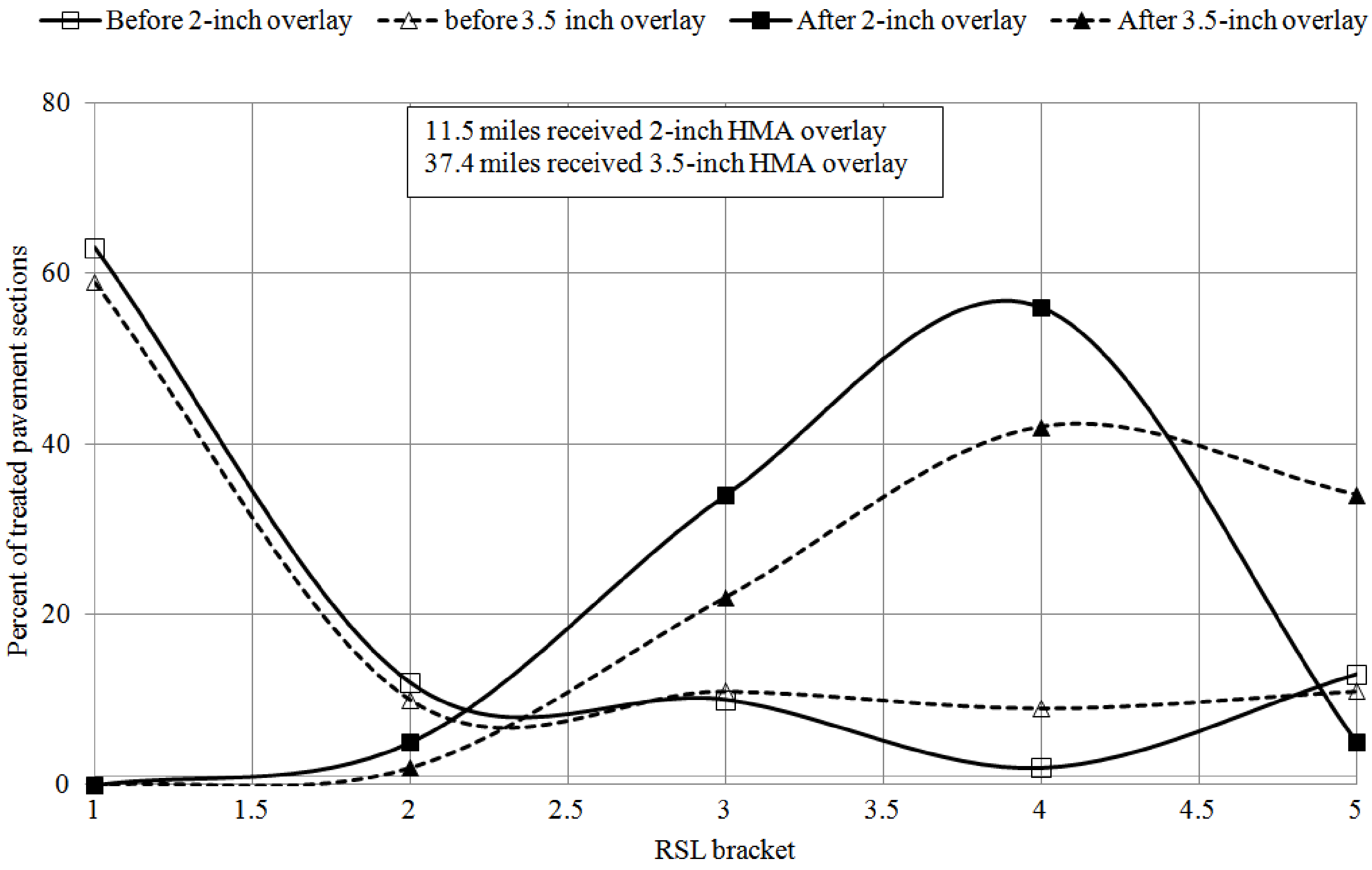


Figure 113
The distribution in the various RSL brackets of the before and after 2-in. and 3.5-in. overlays treatments of alligator cracked arterial road sections

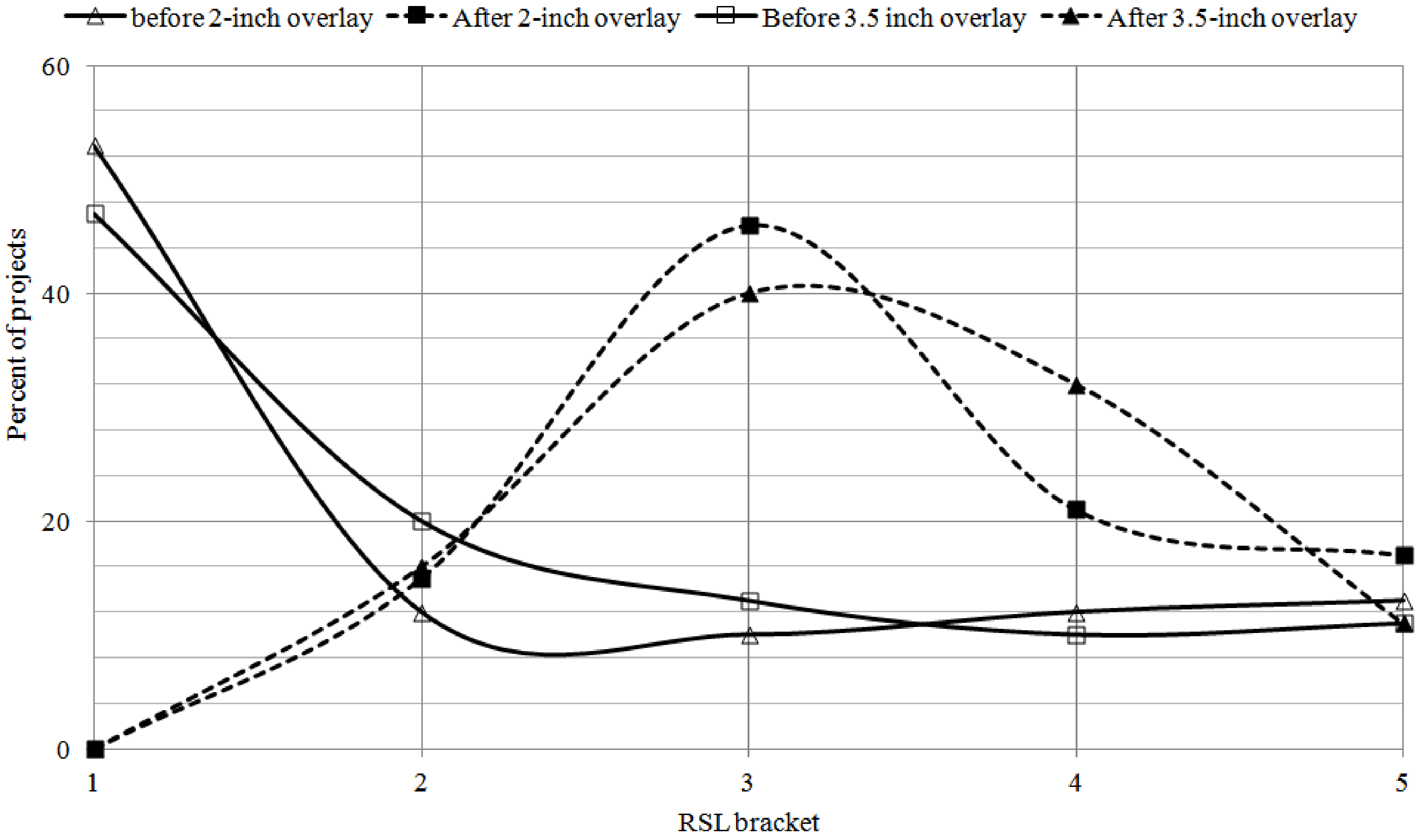


Figure 114

The distribution in the various RSL brackets of the before and after 2-in. and 3.5-in. overlays treatments of alligator cracked collector road sections

2. Transverse, Longitudinal and Random Cracking

The current DOTD deduct points and trigger values for transverse, longitudinal, and random cracking along arterial roads are listed in Table 114. Once again, the DOTD database contained limited pavement performance data regarding the three crack types. The numbers of 0.1 mile long pavement segments where the time dependent data passed the two acceptance criteria are listed below.

1. The before and after treatment time dependent transverse cracking data of 17.2 miles (172 of 0.1 mile pavement segments) that were subjected to 3.5-in. HMA overlay. Unfortunately, the time dependent deduct points data of statistically insignificant 1.8 mile (18 segments) passed the two acceptance criteria.
2. The before and after treatment time dependent longitudinal cracking data of 14 miles (140 of 0.1 mile pavement segments) that were subjected to 3.5-in. HMA overlay. The time dependent deduct points data of statistically insignificant 1.4 mile (14 segments) passed the two acceptance criteria.

The DOTD database did not have statistically significant transverse or longitudinal cracking data for the 2-in. HMA overlay treatment. Time dependent deduct points data based on transverse and longitudinal cracking of only 11 and 2 segments were respectively accepted for analysis. On the other hand, time dependent transverse and longitudinal cracking data of only 26 and 14 segments were respectively accepted for analysis. Hence, the trigger values for 2-in. HMA overlay were not calibrated based on the data.

Table 119 and Table 120 provide lists of the treatment transition matrices data based, respectively, on transverse and longitudinal cracking data and on 3.5-in. HMA overlay treatment. Examination of the data in both tables indicates that the pavement performance after treatment is heavily controlled by the construction practices of these projects. For example:

1. The after treatment data in Table 119 indicate that the conditions of 22% of the 17.2 miles based on RSL worsened and the conditions of another 22% did not change due to the 3.5-in. HMA overlay treatment.
2. The majority of the pavement segments were transferred to RSL bracket 3 regardless of the pre-overlay conditions. This implies that similar construction practices were used for the more than 15 pavement projects.
3. The weighted average service life extension (the difference between the before and after treatment values) of the 3.5-in. overlay treatment is only 3 years versus 9 years for alligator cracking (see Table 118).

4. For most segments, a significant number of transverse cracks reflected through the 3.5-in. HMA overlay within less than 1 year.
5. The construction quality was such that the average after treatment RSL of the majority of the pavement segments (51%) is 8 years, which is almost the same as the average RSL value of the 17.2 mile projects.

Given that the impact of the construction practice on all segments is the same, and given that the effectiveness of the 3.5-in. HMA overlay is almost the same for all segments whose before treatment conditions were in RSL brackets 1, 2, and 3. One can conclude that the trigger values is the average pavement conditions for the three RSL brackets. Such an average is 450 linear ft. of transverse cracks.

Exactly the same scenario can be used describing the before and after treatment data listed in Table 120. Indeed, the 3.5-in. HMA overlay caused almost uniform distribution of the pavement conditions in RSL brackets 2 through 5. Further, the service life extension due to the overlay treatment is only 1 year.

Given the data presented in Table 119 and Table 120 with the associated discussion, the recommended trigger value for transverse, longitudinal, and random cracking and for the 3.5-in. HMA overlay treatment is equal to or greater than 450 linear ft. of cracks. Based on this trigger value, the one for the 2-in. HMA overlay for the three crack types is less than 450 linear ft. These trigger values are listed in Table 114.

Flexible Pavements for Collector and Local Roads. The analyses of the pavement performance of collector and local roads were also conducted in two tiers: based on RSL values that were calculated using the deduct points and based on RSL values that were calculated using the actual distress data. As is the case for the other road classes and for the same reason, the number of pavement segments that passed the two acceptance criteria was much higher for the latter tear. Nevertheless, the DOTD database does not contain statistically sufficient data for the 2-in. HMA overlay on local roads to conduct separate analyses. Therefore, the trigger values for alligator, transverse, longitudinal, and random cracking along collector and local roads were calibrated based on the analyses of the available pavement performance data for the two road class.

1. Alligator Cracking

Currently, the DOTD specify trigger values based on the distress index/deduct points for the four pavement condition or distress types and the four fixes for arterial roads listed in Table

121. Results of the analyses for IRI and rut depths are presented and discussed in earlier segments of this chapter. This section presents and discusses the results of the analyses of the alligator cracking data for collector and local roads.

Table 122 and Table 123 list the treatment transition matrices for 2-in. HMA overlay of flexible pavements along collector roads based on the time dependent deduct points and the actual alligator cracking data, respectively. Once again it can be seen from the two tables that time dependent deduct points data of 218 of 0.1 mile long pavement segments passed the two acceptance criteria (see Table 122) while the time dependent distress data of 401 pavement segments passed the two acceptance criteria (see Table 123). As previously state d, this is mainly due to the high artificial variability induced in the data while adding the deduct points based on the weight factors between the three distress severity levels. Nevertheless, the remaining service life values listed in the before and after treatment segments of Table 122 are based on trigger value of 25 deduct points. Whereas, the remaining service life values listed in the before and after treatment sections of Table 123 are based on alligator cracked area of 1267 ft^2.

The before treatment data listed in Table 122 indicate that the conditions of the 218 pavement segments are equally divided between before treatment RSL brackets 1 and 2. No pavement segments were in very good or excellent conditions before treatment. This observation implies that the trigger value of 25 deduct points (less than 600 ft^2 of alligator cracking) is low. The after treatment data indicate that the pavement segments are distributed mainly in RSL brackets 3, 4, and 5. Further, the data indicate that the average service life extension (SLE) is 11 years. This unreasonably high SLE is mainly due to the low trigger values of 25 deduct points (600 ft^2 of alligator cracking) used in the analysis.

The scenario is much different for the data listed in Table 123. The before treatment data indicate that 53 of the 401 pavement segments were in RSL brackets and just over ten% in each of RSL brackets 2, 3, 4 and 5. The after treatment data indicate that 46% of the 401 pavement segments were transferred to RSL bracket 3 and the rest are distributed in RSL brackets 2, 4, and 5. The data also indicate that the average service life extension (SLE) due to 2-in. overlay is 5 years. This is much more reasonable than the 11 years SLE based on the deduct points. Hence, it appears that the trigger value of 1267 ft^2 of alligator cracking used in the analysis is reasonable. Two other observations can be made from the after treatment data. These are:

Table 119

Treatment transition matrix for 3.5-in. HMA overlay on flexible arterial pavement segments, RSL, transverse cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
						3812	5195	25	2	1			
A	1	0 to 2	74	43	446	**1**	1	46	41	11	9	10	11
B	2	3 to 5	10	6	225	0	**0**	70	20	10	8	6	10
C	3	6 to 10	32	19	171	0	0	**66**	22	13	7	3	11
D	4	11 to 15	27	16	320	0	0	37	**59**	4	7	-2	11
E	5	16 to 25	29	17	216	0	0	55	41	**3**	6	-10	10
F	Total		172	100		1	1	51	39	9	8	3	11

Table 120
Treatment transition matrix for 3.5-in. HMA overlay on flexible arterial pavement segments, RSL, longitudinal cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
						2389	149	24	2	4			
A	1	0 to 2	30	21	305	**0**	0	30	27	43	9	14	15
B	2	3 to 5	17	12	244	0	**6**	29	29	35	9	9	13
C	3	6 to 10	22	16	281	0	5	**27**	41	27	8	5	13
D	4	11 to 15	43	31	69	2	74	14	**5**	5	3	-7	6
E	5	16 to 25	28	20	288	0	0	21	57	**21**	7	-7	13
F	Total		140	100		1	24	23	29	24	7	1	11

Table 121
Existing and calibrated Louisiana trigger values for four distress types in flexible collector roads

Pavement condition/distress	Collector and local roads							
	Treatment type and current DOTD trigger values based on distress and deduct points				Treatment type and calibrated trigger values based on distress and deduct points			
	10	11	12	13	10	11	12	13
Alligator cracking (ft^2)	≤144	≤600	≤1615	>1615	≤144	>144 to ≤800	>800 to ≤1100	> 1100
Transverse cracking (ft)	≤75	>236 to <2087	>2087	-	≤75	>75 to <475	≥475 to <1056	>1056
Longitudinal cracking (ft)	≤75	>236 to <2087	>2087	-	≤75	>75 to <475	≥475 to <1056	>1056
Random cracking (ft)	≤75	>236 to <2087	>2087	-	≤75	>75 to <475	≥475 to <1056	>1056
	Deduct values/distress index				Deduct values[1]/distress index			
Alligator cracking	≤5/≥95	≤25/≥75	≤45/≥55	>45/<55	≤5/≥95	>5 to ≤30/ <95 to ≥70	>30 to ≤38/ <70 to ≥62	>38/<62
Transverse cracking (ft)	≤5/≥95	>20 to ≤30/ <80 to ≥70	>30/<70	-	≤5/≥95	>5 to <26/ <95 to >74	≥26 to ≤27/ ≤74 to ≥ 73	>27/<73
Longitudinal cracking (ft)	≤5/≥95	>20 to ≤30/ <80 to ≥70	>30/<70	-	≤5/≥95	>5 to <26/ <95 to >74	≥26 to ≤27/ ≤74 to ≥ 73	>27/<73
Random cracking	≤5/≥95	>20 to ≤30/ <80 to ≥70	>30/<70	-	≤5/≥95	>5 to <26/ <95 to >74	≥26 to ≤27/ ≤74 to ≥ 73	>27/<73
					Deduct values[2]/distress index			
Alligator cracking					≤7/≥93	>7 to ≤23/ <93 to ≥77	>23 to ≤29/ <77 to ≥71	>29/<71
Transverse cracking (ft)					≤7/≥93	>7 to <26/ <93 to >74	≥26 to ≤48/ ≤74 to ≥52	>48/<52
Longitudinal cracking (ft)					≤7/≥93	>7 to <26/ <93 to >74	≥26 to ≤48/ <74 to >52	>48/<52
Random cracking					≤7/≥93	>7 to <26/ <93 to >74	≥26 to ≤48/ ≤74 to ≥52	>48/<52

[1] Based on the existing deduct values; [2] Based on the recommended deduct values

Treatment type	Description
10	Microsurfacing on collectors
11	Thin overlay on collectors (2" overlay; 0-100 square yards patching)
12	Medium overlay on collectors (cold plane 2", put 3.5" back or just 3.5" overlay, 100-500 square yards patching)
13	In Place Stabilization on Collector; in Place Stabilization and 3" A.C.

Table 122

Treatment transition matrix for 2-in. HMA overlay on flexible collector pavement segments, deduct points, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							29	15	27	36			
A	1	0 to 2	104	48	22	**0**	8	17	35	40	9	13	14
B	2	3 to 5	107	49	27	0	**0**	28	42	30	6	10	14
C	3	6 to 10	7	3	35	0	0	**29**	29	43	7	7	15
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		218	100		0	4	23	38	35	8	11	14

Table 123

Treatment transition matrix for 2-in. HMA overlay on flexible collector pavement segments, RSL, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							1383	781	2	40			
A	1	0 to 2	211	53	649	**0**	25	45	19	10	7	8	9
B	2	3 to 5	50	12	599	0	**2**	60	24	14	7	7	11
C	3	6 to 10	42	10	459	0	10	**55**	14	21	7	3	11
D	4	11 to 15	47	12	327	0	6	34	**51**	9	6	-2	11
E	5	16 to 25	51	13	524	0	2	39	4	**55**	8	-5	15
F	Total		401	100		0	15	46	21	17	7	5	11

1. The 2-in. HMA overlay treatment has better effects on those pavement segments whose pre- treatment conditions were in RSL brackets 2 and 3. These conditions correspond to alligator cracking areas of about 1000 and 600 ft^2.
2. The conditions of about 115 pavement segments (about 35% of the 401 segments) were worsened or unaffected due to the treatment.

Based on the results of the analyses, the trigger value for 2-in. HMA treatment of alligator cracked collector roads was calibrated to 800 ft^2. Based on the existing DOTD deduct point systems, this corresponds to a maximum of 27 deduct points or to a minimum alligator cracking index of 73. On the other hand, based on the recommended deduct point systems, this correspond to a maximum of 23 deduct points or to a minimum alligator cracking index of 77.

Table 124 and Table 125 list the treatment transition matrices for 3.5-in. HMA overlay of flexible pavements along collector roads based on the time dependent deduct points and the actual alligator cracking data, respectively. Once again it can be seen from the two tables that time dependent deduct points data of 626 of 0.1 mile long pavement segments passed the two acceptance criteria (see Table 124) while the time dependent distress data of 1291 pavement segments passed the two acceptance criteria (see Table 125). As stated before, this is mainly due to the high artificial variability induced in the data while adding the deduct points based on the weight factors between the three severity levels of alligator cracking. Nevertheless, the remaining service life values listed in the before and after treatment sections of Table 124 are based on trigger value of 35 deduct points. Whereas, the remaining service life values listed in the before and after treatment sections of Table 125 are based on alligator cracked area of 1267 ft^2.

The before treatment data listed in Table 124 indicate that the pavement conditions of the 626 pavement segments are equally distributed in RSL brackets 1, 2 and 3. This observation implies that the trigger value of 35 deduct points (less than 960 ft^2 of alligator cracking) is relatively low. The after treatment data indicate that 67% of the 626 segments were moved to RSL bracket 5 (excellent condition), 22% to bracket 4 and 10% to bracket 3. Further, the data indicate that the average service life extension (SLE) is 13 years. This unreasonably high SLE is mainly due to the low trigger values of 35 deduct points (960 ft^2 of alligator cracking) used in the analysis.

Table 124
Treatment transition matrix for 3.5-in. HMA overlay on flexible collector pavement segments, deduct, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							37	15	21	37			
A	1	0 to 2	210	34	24	**0**	1	10	27	62	9	16	17
B	2	3 to 5	232	37	25	0	**1**	7	14	78	8	14	18
C	3	6 to 10	161	26	30	0	2	**10**	27	61	8	9	17
D	4	11 to 15	8	1	37	0	13	25	**25**	38	4	0	13
E	5	16 to 25	15	2	41	0	0	20	20	**60**	4	-4	16
F	Total		626	100		0	1	10	22	67	8	13	17

Table 125

Treatment transition matrix for 3.5-in. HMA overlay on flexible collector pavement segments, RSL, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
							1742	293	8	7			
A	1	0 to 2	602	47	407	**0**	16	43	28	13	8	9	10
B	2	3 to 5	252	20	391	0	**12**	37	42	10	8	7	11
C	3	6 to 10	171	13	351	0	18	**40**	33	9	7	2	10
D	4	11 to 15	126	10	385	0	25	39	**29**	7	6	-4	9
E	5	16 to 25	140	11	589	0	19	39	31	**11**	7	-10	10
F	Total		1291	100		0	16	40	32	11	8	5	10

The data listed in Table 125 indicate that 46% of the 1291 pavement segments were in RSL bracket 1, 20% in bracket 2 and slightly more than 10% in each of RSL brackets 3, 4, and5. The before treatment data indicate that 53 of the 401 pavement segments were in RSL brackets and just over 10% in each of RSL brackets 2, 3, 4 and 5. The after treatment data indicate that only 11% of the 1291 pavement segments were transferred to RSL bracket 5, 32% to bracket 4, and 40% to RSL bracket 3. Finally, the data show that the average service life extension (SLE) due to 3.5-in. overlay is 5 years, which is the same as the SLE for 2-in. HMA overlay (see Table 123). This was not expected and it could be due to the trigger value which was set at 1267 ft^2. Two other observations can be made from the after treatment data. These are:

1. The 3.5-in. HMA overlay treatment has slightly better effects (higher after treatment RSL) on those pavement segments whose pre- treatment conditions were in RSL brackets 2 than in the other brackets. This corresponds to alligator cracking areas of about 1100 ft^2.
2. The conditions of about 385 pavement segments (about 32% of all projects) worsened or were not affected by the treatment.

Based on the results of the analyses, the trigger value for the 3.5-in. HMA treatment of alligator cracked collector roads was calibrated to a maximum of 1100 ft^2, which is the same as the average existing DOTD trigger value (>600 to <1615 ft^2). Nevertheless, based on the existing DOTD deduct point systems, the 1100 ft^2 alligator cracking corresponds to a maximum of 38 deduct points or to a minimum alligator cracking index of 62 (the current values are 25 to 45 deduct points and alligator cracking index between 55 and 75). On the other hand, based on the recommended deduct point systems (see Chapter 1) the 1100 ft2 alligator cracks correspond to a maximum of 29 deduct points or to a minimum alligator cracking index of 71.

Similar before and after treatment observations were made relative to the 3.5-in. HMA overlay of local roads. The data are listed in Table 126 and Table 127. Table 126 is based on the time dependent deduct points with a trigger value of 35 deduct points while the data in Table 127 are based on the actual alligator cracking data and a threshold value of 1267 ft^2. Unfortunately, statistically insignificant amount of time dependent deduct points or alligator cracking data were found in the DOTD database. However, since the data for the 3.5-in. HMA overlay on local roads are similar to the 3.5-in. HMA overlay on collectors, the trigger values for the 2-in. HMA overlay of local roads were assumed to be the same as those for collector roads. The calibrated trigger values are listed in Table 121.

Table 126

Treatment transition matrix for 3.5-in. HMA overlay on flexible Local pavement segments, deduct, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
								17	19	35			
A	1	0 to 2	132	64	30	**0**	0	16	15	69	9	16	17
B	2	3 to 5	42	20	29	0	**0**	12	10	79	8	14	18
C	3	6 to 10	31	15	31	0	0	**23**	29	48	7	7	15
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		205	100		0	0	16	16	68	9	14	17

Table 127

Treatment transition matrix for 3.5-in. HMA overlay on flexible Local pavement segments, RSL, alligator cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
							2140	513	13	5			
A	1	0 to 2	153	61	782	**0**	4	78	14	4	8	8	9
B	2	3 to 5	24	10	424	0	**13**	63	17	8	7	5	9
C	3	6 to 10	20	8	345	0	20	**80**	0	0	5	-1	7
D	4	11 to 15	31	12	317	0	65	35	**0**	0	3	-8	5
E	5	16 to 25	22	9	436	0	14	59	18	**9**	7	-11	9
F	Total		250	100		0	14	70	12	4	7	3	8

2. Transverse, Longitudinal, and Random Cracking

The current DOTD deduct points and trigger values for transverse, longitudinal, and random cracking along arterial roads are listed in Table 121. Fortunately, the DOTD database contained adequate pavement performance data regarding the three crack types. Once again, the analyses were conducted in two tears; one tear is based on the RSL values calculated using the time dependent deduct points and the other on the RSL values calculated using the actual distress data.

Table 128 and Table 129 provide lists of the treatment transition matrices data for 2-in. HMA overlay of transverse cracked flexible collector roads. The two tables are based, respectively, on RSL values calculated using the DOTD deduct points and on the RSL values calculated using the actual crack lengths. The former is based on a trigger value of 25 deduct points (about 290 ft. of transverse cracks) while the latter is based on a threshold value of 528 ft. of cracking. Examination of the data listed in Table 128 and Table 129 indicate that:

1. In Table 128, 110 of 0.1 mile long pavement segments were accepted based on the time dependent deduct points approach while 159 segments were accepted based on the time dependent transverse cracking data approach (see Table 129).
2. The before treatment conditions in Table 128 are distributed between RSL brackets 1, 2, and 3, and among RSL brackets 1 through 5 in Table 129. This is mainly due to the low trigger value used by the DOTD.
3. The condition of 75% (42 pavement segments) of the 0.1 mile long pavement segments (see Table 128) that were in RSL bracket 1 improved to RSL bracket 5 due to the treatment. Whereas 26 and 16 pavement segments in RSL brackets 2 and 3 before treatment transferred, respectively, transferred to RSL bracket 5.
4. On the other hand, the before and after treatment data listed in Table 129 indicate that only one 0.1 mile long pavement segment transferred from before treatment RSL bracket 1 to RSL bracket 5, whereas 4 transferred from RSL bracket 2 to RSL bracket 5. In addition, the after treatment RSL value is maximized when the treated pavement segments were in RSL bracket 2 before treatment.

The above observations indicate that the trigger value used in Table 128 (290 ft.) is low and the threshold value used in Table 129 (528 ft.) is slightly higher. Therefore, the calibrated trigger value for 2-in. overlay of transverse cracked collector and local roads is 475 ft., which is the before treatment lengths of transverse cracks of RSL bracket 2. This calibrated trigger value based on transverse length corresponds to the existing DOTD trigger value of 26 deduct points. Based on the recommended deduct point system, the 475 ft. of transverse cracks correspond to 26 deduct points also.

Unfortunately, no statistically significant time dependent deduct points data were found in the DOTD database for 2-in. HMA overlay on longitudinal cracking. Data for only 1.9 miles were located. However, time dependent longitudinal cracking data include 15.4 miles that received 2-in. HMA overlay were located and analyzed. The results are listed in Table 130. It can be seen that the data in the table are more or less similar to the data in Table 129. Hence, the trigger value for the 2-in. HMA overlay over longitudinal cracked pavements is also 425 ft.

Table 128

Treatment transition matrix for 2-in. HMA overlay on flexible collector pavement segments, deduct points, transverse cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
								10	19	27			
A	1	0 to 2	64	58	20	**0**	0	13	13	75	10	17	18
B	2	3 to 5	26	24	20	0	**0**	0	0	100	10	16	20
C	3	6 to 10	20	18	24	0	0	**10**	10	80	8	10	18
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		110	100		0	0	9	9	82	9	15	18

Table 129

Treatment transition matrix for 2-in. HMA overlay on flexible collector pavement segments, RSL, transverse cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							544	102	46	3			
A	1	0 to 2	72	45	326	**0**	11	85	3	1	8	7	8
B	2	3 to 5	21	13	193	0	**5**	76	0	19	7	6	10
C	3	6 to 10	19	12	157	0	5	**95**	0	0	6	0	8
D	4	11 to 15	32	20	72	0	6	91	**3**	0	5	-5	8
E	5	16 to 25	15	9	484	0	0	87	7	**7**	6	-11	9
F	Total		159	100		0	8	86	3	4	7	2	8

Table 130
Treatment transition matrix for 2-in. HMA overlay on flexible collector pavement segments, RSL, longitudinal cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
							52	25	6	1			
A	1	0 to 2	42	35	360	**0**	0	86	14	0	9	8	9
B	2	3 to 5	16	13	235	0	**0**	81	19	0	8	5	9
C	3	6 to 10	19	16	215	0	0	**89**	11	0	8	1	9
D	4	11 to 15	34	28	147	0	6	88	**3**	3	6	-5	8
E	5	16 to 25	10	8	542	0	0	70	20	**10**	7	-10	10
F	Total		121	100		0	2	85	12	2	8	1	9

For the 3.5-in. HMA overlay treatment, the time dependent pavement performance data were analyzed using the DOTD trigger value of 30 deduct points, which corresponds to about 2100 ft. of transverse cracks and the actual time dependent transverse cracking data. Results of the analyses are listed in Table 131 and Table 132. The after treatment data in Table 131 indicate that the benefits of the 3.5-in. HMA overlay treatment in terms of treatment life (TL), service life extension (SLE), and remaining service life (RSL) are the highest for all pavement segments that were in RSL bracket 1 before treatment. The benefits decline as the before treatment RSL increases (transverse cracking less than 2100 ft.). This indicates that the DOTD trigger value of 2100 ft. of transverse cracking is properly selected. Further, the data in Table 131 indicate that, on average, the life of the 3.5-in. HMA overlay is about 10 years and the weighted average service life extension is 14 years. These results are very reasonable and agree with the filed observations of pavement performance.

The results in Table 132, on the other hand, which were based on a threshold value of 528 ft. of transverse cracks, indicate that the threshold value is very low. The pavement conditions of most treated pavement segments are in RSL brackets 2, 3, and 4. The conditions of only 10% of the 86.6 mile projects were improved to RSL bracket 5. Once again, the results indicate that the threshold value is very low.

Based on the results of the analyses presented in Table 131 and Table 132, the calibrated trigger value for 3.5-in. HMA overlay and transverse cracking on collector and local roads is 2100 ft. of cracks. However, 2100 ft. of transverse cracks in 0.1 mile pavement segment correspond to 175 cracks with crack spacing of only 3 ft. Such crack spacing would adversely impact the ride quality. Hence, it is recommended that the trigger value be set at crack spacing of 6 ft. (which is equivalent to half of the lane width). That would make the number of cracks in a 0.1 mile long pavement segment 88 cracks. Based on this discussion, it is recommended that the trigger value for transverse cracks and 3.5-in. HMA overlay treatment be set at 1056 ft. Based on the existing DOTD deduct point system, this corresponds to a trigger value of 27 deduct points. Based on the deduct points recommended, the 1056 transverse cracks correspond to 48 deduct points.

Results of the analyses of the time dependent pavement performance based on deduct points and longitudinal cracking length for 3.5-in. HMA overlay treatments are listed in Table 133 and Table 134. Examination of the data in the two tables leads to the same recommendations made for transverse cracking and 3.5-in. HMA overlay treatment. Hence the recommended trigger value for longitudinal cracked collector and local roads is 1056 ft. of cracks. This corresponds to two longitudinal cracks along the entire length of a 0.1 mile long pavement segment. Once again, the 1056 ft. of longitudinal cracking corresponds to 27 deduct points based on the existing DOTD deduct point system and to 48 deduct points based on the deduct point system recommended before.

The above recommendations for transverse and longitudinal cracking along collector roads were verified using the time dependent performance data collected along local roads. Unfortunately, no statistically significant data were available in the DOTD database for the 2-in. HMA overlay treatment. However, data for the 3.5 in. HMA overlay were located and analyzed. Results of the analyses are listed in Table 135 through Table 137. Detailed examination of the results listed in these tables indicates that the benefits of the 3.5-in. HMA overlay treatments on local roads are more or less similar to those on collector roads. Hence, the trigger values for local roads are the same as those recommended for collector roads.

Table 131
Treatment transition matrix for 3.5-in. HMA overlay on flexible collector pavement segments, deduct points, transverse cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
								12	15	29			
A	1	0 to 2	92	30	28	**0**	0	5	9	86	10	18	19
B	2	3 to 5	166	54	19	0	**0**	6	18	76	8	14	18
C	3	6 to 10	38	12	22	0	0	**37**	5	58	6	7	15
D	4	11 to 15	12	4	27	0	0	42	**8**	50	6	1	14
E	5	16 to 25	0	0									
F	Total		308	100		0	0	11	13	76	8	14	18

Table 132

Treatment transition matrix for 3.5-in. HMA overlay on flexible collector pavement segments, RSL, transverse cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							851	111	4	3			
A	1	0 to 2	387	45	379	**0**	13	45	28	14	8	9	10
B	2	3 to 5	162	19	214	0	**14**	54	23	9	7	6	10
C	3	6 to 10	133	15	236	0	14	**54**	28	4	6	1	9
D	4	11 to 15	73	8	256	0	15	47	**36**	3	6	-3	10
E	5	16 to 25	111	13	222	0	4	57	29	**11**	6	-9	11
F	Total		866	100		0	12	50	28	10	7	4	10

Table 133

Treatment transition matrix for 3.5-in. HMA overlay on flexible collector pavement segments, deduct points, longitudinal cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
			Number	Percent				9	15	28			
A	1	0 to 2	41	27	23	**0**	0	10	5	85	9	17	18
B	2	3 to 5	68	44	18	0	**0**	6	9	85	8	15	19
C	3	6 to 10	40	26	26	0	0	**40**	10	50	4	7	15
D	4	11 to 15	4	3	26	0	0	0	**0**	100	9	7	20
E	5	16 to 25	1	1	32	0	0	0	0	**100**	10	0	20
F	Total		154	100		0	0	16	8	77	8	13	18

Table 134
Treatment transition matrix for 3.5-in. HMA overlay on flexible collector pavement segments, RSL, longitudinal cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							339	74	3	7			
A	1	0 to 2	219	30	283	**0**	18	45	16	20	8	10	11
B	2	3 to 5	151	21	96	0	**12**	42	26	20	7	7	11
C	3	6 to 10	121	17	107	0	12	**39**	22	26	7	4	12
D	4	11 to 15	101	14	145	0	14	60	**18**	8	6	-4	9
E	5	16 to 25	128	18	160	0	4	42	30	**23**	6	-8	12
F	Total		720	100		0	13	45	22	20	7	3	11

Table 135

Treatment transition matrix for 3.5-in. HMA overlay on flexible local pavement segments, deduct points, transverse cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
								8	13	27			
A	1	0 to 2	11	11	28	**0**	0	27	9	64	8	15	16
B	2	3 to 5	73	74	23	0	**0**	11	12	77	8	14	18
C	3	6 to 10	14	14	20	0	0	**7**	0	93	6	11	19
D	4	11 to 15	1	1	27	0	0	0	**0**	100	10	7	20
E	5	16 to 25	0	0									
F	Total		99	100		0	0	12	10	78	8	14	18

Table 136

Treatment transition matrix for 3.5-in. HMA overlay on flexible local pavement segments, RSL, transverse cracking

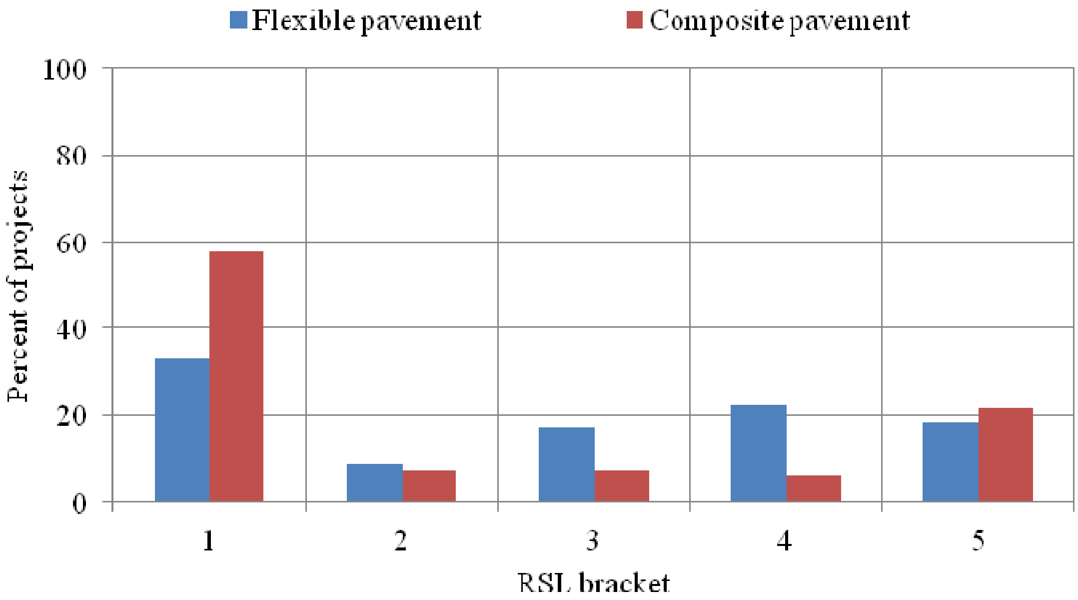
Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
							309	132	6	1			
A	1	0 to 2	117	38	423	**0**	5	65	22	8	8	9	10
B	2	3 to 5	61	20	82	0	**3**	74	13	10	7	6	10
C	3	6 to 10	39	13	80	0	10	**64**	23	3	6	1	9
D	4	11 to 15	53	17	109	0	47	51	**0**	2	4	-7	6
E	5	16 to 25	35	11	145	0	6	71	14	**9**	4	-10	10
F	Total		305	100		0	13	65	16	7	6	2	9

Table 137

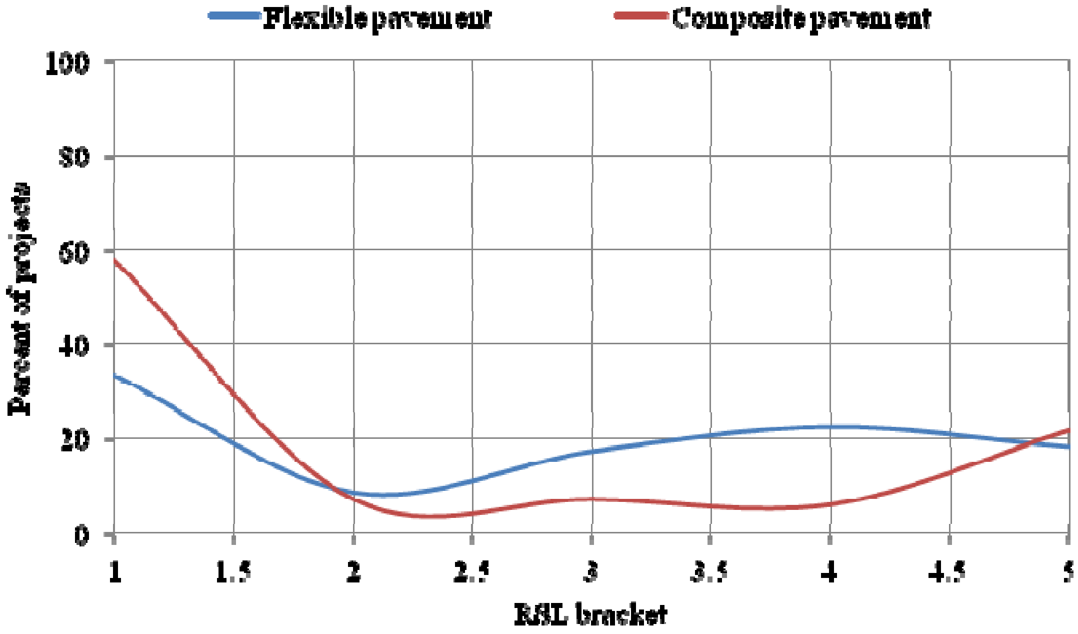
Treatment transition matrix for 3.5-in. HMA overlay on flexible local pavement segments, deduct points, longitudinal cracking

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
								10	14	26			
A	1	0 to 2	6	12	24	**0**	0	0	0	100	10	19	20
B	2	3 to 5	38	75	18	0	**0**	3	16	82	8	15	19
C	3	6 to 10	7	14	25	0	0	**43**	14	43	5	6	14
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		51	100		0	0	8	14	78	8	14	18

Composite Pavements. In the previous sections, it was recommended that the trigger values for IRI and rut depth for composite pavements are the same as those for flexible pavements. In this section, it is recommended that the trigger values for transverse, longitudinal, and random cracking in composite pavement be the same as those for flexible pavements. The main reason is that the actual before and after treatment distributions of the pavement conditions along composite and flexible pavement projects are more or less similar. Examples of the before and after treatment similarities of the distributions of the pavement conditions are shown in Figure 115 and Figure 116. The two figures are for pavement projects along arterial roads that were subjected to 3.5-in. overlay, respectively. Analyses of the before and after treatment distributions of the conditions of flexible and composite pavements along arterial roads that received 2-in. overlay and along collector roads that received 3.5-in. and 2-in. overlay treatments showed similar results.



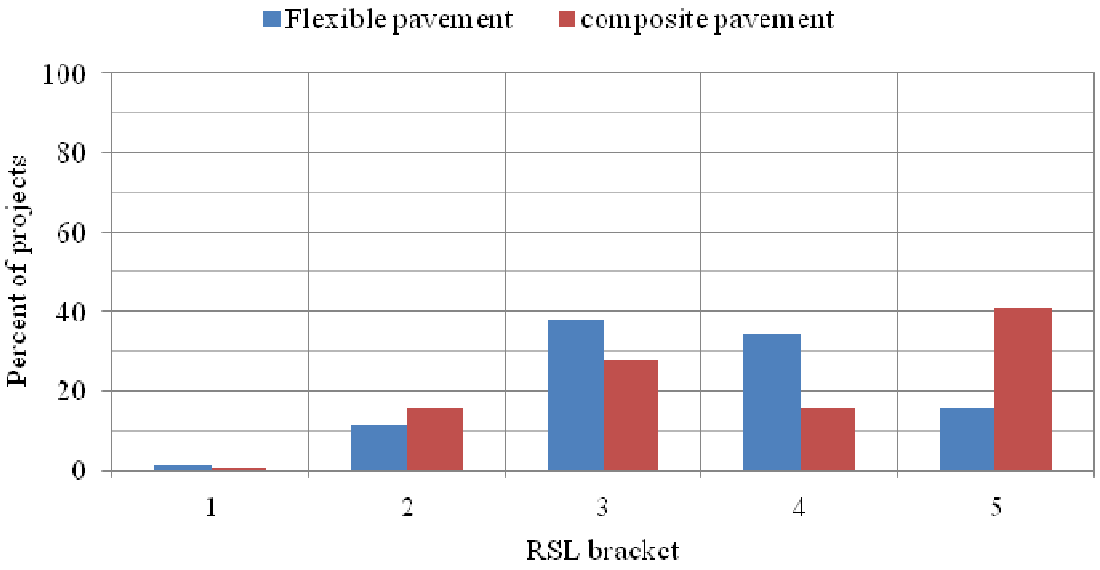
a) Bar chart format



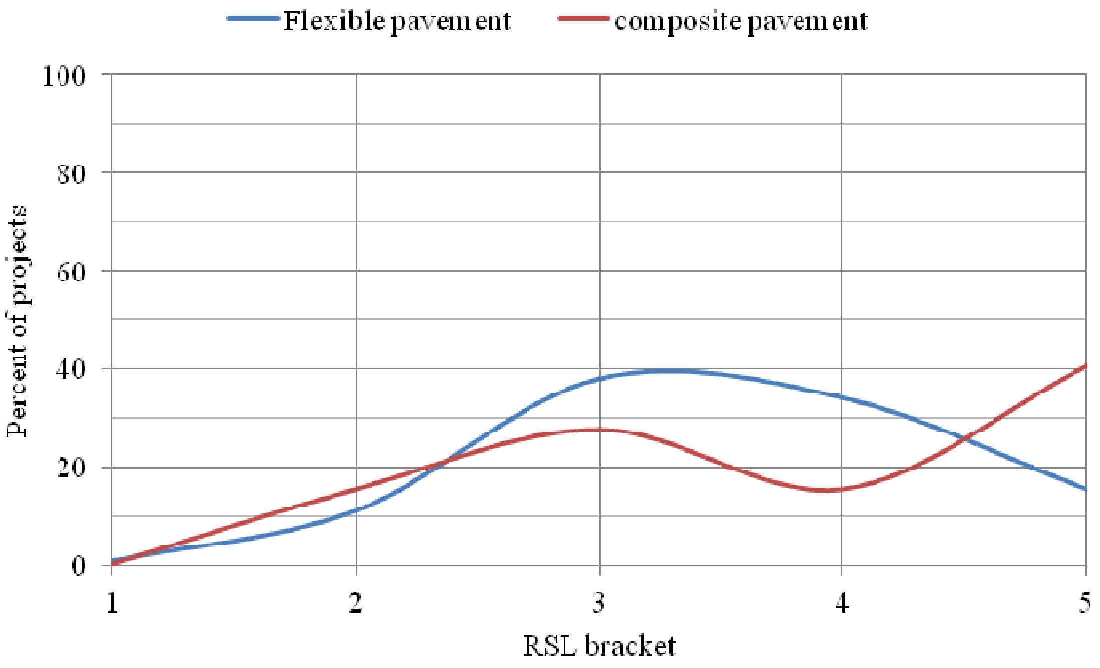
b) Continuous presentation format

Figure 115

Before treatment distributions of random cracking on various flexible and composite pavement projects



a) Bar chart format



b) Continuous presentation format

Figure 116

After treatment distributions of random cracking on various flexible and composite pavement projects

Trigger Values for Chipseal

Current Chipseal Practice. The DOTD pavement preservation program consists of various pavement preservation treatments including single, double, and triple chipseals. Although trigger values based on the pavement deduct points are used for the selection of the pavement preservation types and the pavement projects, no trigger values have been established for the selection of chipseal treatment type relative to the pavement condition and distress. The DOTD applies chipseal treatments to mainly collectors and local roads and to very much limited sections along the arterial roads and the Interstates. This is evident from the amount of pavement performance data available in the DOTD database. While the database contains pavement performance data of hundreds of miles of collector and local roads, it has no statistically significant pavement performance data (but for few miles) regarding chipsealed arterial roads or Interstates. Therefore, the material in this chapter presents and discusses new sets of trigger values based on deduct points that could be used in the selection of the chipseal treatment type and the boundaries of the pavement projects along collector and local roads only. The new sets of trigger values are based on the analysis of the available pavement performance data of flexible and composite collector and local roads that received chipseal treatments in the past. The analyses were based on the following two sets of trigger values:

1. The first set of trigger values are based to certain extent on the trigger values for microsurfacing treatment. These are 22.5 deduct points for rut depth, 5 deduct points for each of alligator, transverse, and/or longitudinal cracking and 20 deduct points for IRI.
2. The second set of trigger values are 22.5 deduct points for rut depth, 15 deduct points for alligator cracking, 12.5 deduct points for each of transverse, longitudinal, and random cracking, and 20 deduct points for IRI.

Trigger Values for Chipseal on Flexible Pavements

Single Chipseal Treatment. Table 139 through Table 146 present the treatment transition matrices for single chipseal treatment applied to flexible collector roads. Table 139 is for rut depths, Table 140 and Table 141 are for alligator cracking, Table 142 and Table 143 are for transverse cracking, and Table 144 and Table 145 are for longitudinal cracking and Table 146 for IRI. Table 147 through Table 154 present the same sequence of treatment transition matrices for flexible local roads. Once again, each treatment transition matrix is based on certain pavement condition and distress type. Each matrix is divided into three sections as follows:

1. Before treatment section that contains the RSL brackets and their ranges, and the before treatment number and distribution of the various 0.1 mile long pavement segments of the projects in the various RSL brackets. Such distribution is based on

the DOTD deduct points and the threshold trigger values for microsurfacing. The section also houses the standard errors of the best-fit model.

2. After treatment section that contains the RSL brackets and their ranges, and the before treatment number and distribution of the various 0.1 mile long pavement segments of the projects in the various RSL brackets. Such distribution is also based on the DOTD deduct points and the threshold trigger values for microsurfacing. Once again, this section also houses the standard errors of the best fir model of the after treatment data.
3. The treatment benefits section in terms of treatment life (TL), service life extension (SLE) and remaining service life (RSL). For more details please see Chapter 2 and the rut depth section below.

1. Rut Depth

1. The treatment transition matrix in Table 139 shows that 1869 of 0.1 long pavement segments (186.9 miles) were treated using single chipseal treatment. The before treatment condition of 32% of all projects or 606 of the 1869 segments were in RSL category 1 (0.0 to 2 years of life). This corresponds to deduct points of higher than 20 points. The condition states of 8% of the 1869 segments are in each of RSL brackets 2 (RSL from 3 to 5 years), 3 (RSL from 6 to 10 years), and 4 (RSL from 11 to 15). Finally, 43% of the 1869 segments are in RSL bracket 5 (RSL longer than 16 years).

2. Each row in the after treatment section of Table 139 lists the distribution in the after treatment RSL brackets of the 0.1 mile long pavement segments in each before treatment RSL bracket. To illustrate, the 606 segments (60.6 miles) in the before treatment RSL bracket 1 (see Table 139) are distributed in the after treatment brackets as follows: 9% in RSL bracket 1, 12% in 2, 10% in 3, 5% in 4 and 63% in bracket 5. This implies that the rut problem of 63% of the 606 segments having more than 0.4-in. rut depth before treatment was effectively treated while the single chipseal treatment did not have any effects on 9% of the 606 segments.

3. The lowest percentage listed in the after treatment section under RSL bracket 5 (excellent condition) is associated with the poor before treatment pavement condition (RSL from zero to 2 years). This implies that the single chipseal treatment is least effective when applied to pavement segments in poor condition and more effective when the pre-treatment pavement conditions are in higher RSL brackets or have lower rut depths.

The above observations indicate that to increase the effectiveness of a single chipseal treatment against rutting, the maximum trigger value based on rut depth deduct points should be set at 20. This corresponds to rut depths of less than 4-in.

2. Cracking

The analyses of the effectiveness of single chipseal treatment for alligator, transverse, and longitudinal cracking was analyzed using two trigger values for each distress type. The results are presented below.

a) **Alligator Cracking** –Two trigger values are used in the analysis of alligator cracking; 5 deduct points and 15 deduct points. The data listed in the before treatment section of Table 140 indicate that the entire pavement projects (2553 of 0.1 mile pavement segments or 255.3 miles) are in RSL bracket 1 (RSL of 0.0 to 2 years). After treatment, 14% remained in RSL bracket 1 (no gain), 56% moved to RSL bracket 2 (an average gain of 3 years) and 28% moved to RSL bracket 3 (an average gain of 7 years). The results in Table 141 are based on trigger value of 15 deduct points. It can be seen that 2482 of 0.1 mile pavement segments were in RSL bracket 1 before treatment (a slight decrease from the 2552 of Table 140). The results in the after treatment section of Table 141 indicate that the condition of all the 2482 0.1-mile pavement segments that were in RSL bracket 1 before treatment improved. Twenty one percent moved to RSL bracket 2 (a gain of 3 years), 56% to bracket 3 (a gain of 7 years) and the rest to higher RSL brackets. The results in the table also indicate that the condition state of 64% of the 55 pavement segments (5.5 miles) that were in RSL brackets 2 improved to RSL bracket 3 while 81% of the 16 segments that were in RSL bracket 3 stayed in bracket 3. Examination of the results listed in Table 140 and Table 141 indicate that the trigger value for alligator cracking should be set at a maximum of 15 deduct points. Such trigger value would maximize the benefits from the single chipseal treatment.

One other point that should be noted herein is that the reason that the after treatment condition state of some pavement segments is in high RSL brackets is mainly due to their low rates of deterioration for the period where alligator cracking data after treatment are available in the DOTD database.

b) **Transverse and Longitudinal Cracking**- Like alligator cracking, the analyses of transverse and longitudinal cracking data were accomplished using two trigger values for each; 5 deduct points (which is the microsurfacing trigger value) and 12.5 deduct points. The results are listed in Table 142 and Table 143 for transverse cracking and in Table 144 and Table 145 for longitudinal cracking.

The results in Table 142 indicate that the before treatment condition of all 925 segments are in RSL bracket 1. This is mainly due to the low trigger value of 5 deduct points used in the analysis. Based on such trigger value, the single chipseal treatment caused 61% of the 925 segments to move to RSL bracket 2 (3 to 5 years of life with an average of 4 years). Hence, the net gain is about 3 years. When the trigger value increased to 12.5 (see Table 143), 48% of the segments in RSL bracket 1 before treatment moved to RSL bracket 3 after treatment. However, 85% of the segments in RSL bracket 2 before treatment moved to RSL bracket 3 after treatment. Thus, for transverse cracking, a trigger value corresponds to RSL bracket 2 is more desirable. This is equivalent to deduct points of 10 points or less.

Table 144 and Table 145 present the treatment transition matrices for longitudinal cracking. The results in Table 144 indicate that the before treatment condition state of all 642 pavement segments (64.2 miles) was RSL bracket 1. Once again, this is due to the low trigger value of 5 deduct points. However, the single chipseal treatment moved the majority or 56% of the segments to RSL bracket 3 (RSL between 6.0 and 10 years, with an average of 8 years). The results in Table 145, which are based on trigger value of 12.5 deduct points, indicate that, before treatment, 96% of the 64.2 miles was in RSL bracket 1 and 4% in RSL bracket 2. Whereas, the after treatment data indicate that the condition state of 48% of the 61.5 miles improved from RSL bracket 1 to RSL bracket 3 and 32% to RSL bracket 4. In addition, 42% of 2.6 miles improved from RSL bracket 2 to RSL bracket 3 and 50% to RSL bracket 4 (average RSL of 13 years).

Examination of the combined results presented in Table 140 through Table 145 indicates that:

1. The single chipseal treatment is more effective for longitudinal cracking than for alligator and transverse cracking.
2. The single chipseal treatment is more effective for transverse cracking than for longitudinal cracking.
3. The best trigger for longitudinal and transverse cracking is 10 deduct points.

3. International Roughness Index (IRI)

Finally, the treatment transition matrix of Table 146 is based on the IRI data and trigger value of 20 deduct points, which corresponds to IRI of 150 inch/mile. The before treatment data indicate that 862 of the 2214 treated pavement segments where in RSL bracket 1 (RSL between 0.0 and 2 years). This correspond to IRI of 140 inch/mile or higher. The after treatment data in Table 146 indicate that 72 percent of these 862 segments remained in RSL bracket 1. This implies that the single chipseal treatment is not effective when it is applied to pavement segments having IRI of 140 inch/mile or higher. The effectiveness of the single chipseal treatment increases substantially as the before treatment RSL bracket increase to 3 (RSL of 6 to 10 years) which correspond to IRI of less than or equal to 125 inch/mile. Hence, the suggested trigger values for IRI and single chipseal treatment are 125 inch/mile or 15 deduct points.

Similar scenarios (see Table 147 through Table 154) were found for the single chipseal treatment of local roads. Hence, the recommended trigger values for local roads are the same as those recommended for collector roads.

Table 154 provides a summary list of the recommended trigger values based on deduct points and the actual distress values. The current trigger values in the table are those for microsurfacing.

Double Chipseal Treatment. Table 155 through Table 162 present the treatment transition matrices for double chipseal treatment applied to flexible collector roads. Like the single chipseal treatment, Table 155 is based on rut depths, Table 156 and Table 157 are for alligator cracking, Table 158 and Table 159 are for transverse cracking, Table 160 and Table 161 are for longitudinal cracking, and Table 162 for IRI. Table 163 through Table 170 present the same sequence of treatment transition matrices for local roads. Once again, each of the treatment transition matrices listed in Table 155 through Table 170 is based on certain pavement condition and distress type and it consists of similar information or data as those presented under the single chipseal heading. Please note that the DOTD database for double chipseal treatment on collector roads contains much more pavement sections than for the double chipseal treatment on local roads.

Examination of the before and after treatment data listed in Table 155 through Table 170 indicate that the effectiveness of the double chipseal treatment on the conditions and distresses of the treated pavement segments is just slightly better than that for a single chipseal treatment. All observations made for the single chipseal treatment relative to rut depths, alligator, transverse and longitudinal cracking and IRI are almost the same as those made regarding the data for the double chipseal treatment. Therefore, the recommended trigger values are the same as those for the single chipseal treatment.

Triple Chipseal Treatment. Unfortunately, there are very limited data regarding the performance of triple chipseal treatment. The DOTD database contains pavement performance data of less than 2.5 miles of collector roads that were subjected to triple ship seal treatment. Results of the analyses are listed in Tables 164 and 165 for rut depth and IRI, respectively. The limited results do not support, with a strong confidence level, the establishment of trigger values for triple chipseal. Therefore, the trigger values for single chipseal are also recommended for the triple chipseal.

Trigger Values for Chipseal Treatment on Composite Pavement

Although much less data are available in the DOTD database regarding the pavement performance of chipseal treatments of composite pavements, as it was expected, the results of the analyses show similar trends to those for flexible pavements. Such results are not presented herein to avoid unnecessary duplication. Based on the results of the analysis of composite pavement performance sections that received chipseal treatment, the recommended trigger values for composite pavements are the same as those for flexible pavements.

Summary of Chipseal Treatment Trigger Values

The new trigger values based on deduct points for chipseal treatments are summarized below.

Table 138

Summary of chipseal treatment trigger values

Road class	Distress/ condition	Type of cracks	Single, double or triple chipseal treatments		
			Deduct points	Condition	
				Existing	Modified[1]
Collector and Local	Rut depth (in.)		20	<0.4	<0.4
	IRI(inch/mile)		15	<125	<125
	Cracking	Alligator(ft^2)	15	<400	<250
		Transverse(ft)	10	<190	<118
		Longitudinal(ft)	10	<190	<118
		Random(ft)	10	<190	<118
Arterial	No significant data available in the DOTD database				
Interstate	No significant data available in the DOTD database				
[1] See state -of-the-practice section					

Table 138
A single chipseal treatment transition matrix based on trigger value of 22.5 deduct points for rut depths in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in)							
						8.80	4.62	3.57	4.00	2.93			
A	1	0 to 2	606	32	9.14	**9**	12	10	5	63	9	14	15
B	2	3 to 5	154	8	5.55	2	**4**	6	5	83	8	14	18
C	3	6 to 10	153	8	4.62	3	9	**10**	7	71	5	8	16
D	4	11 to 15	158	8	5.00	1	8	13	**4**	74	4	4	17
E	5	16 to 25	798	43	4.60	2	5	8	5	**80**	4	-3	17
F	Total		1869	100		4	8	9	5	74	6	6	16

Table 139

A single chipseal treatment transition matrix based on trigger value of 5 deduct points for microsurfacing of alligator cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
						34	19	32	39				
A	1	0 to 2	2553	100	29	**14**	56	28	2	0	8	4	5
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		2553	100		14	56	28	2	0	8	4	5

Table 140
A single chipseal treatment transition matrix based on trigger value of 15 deduct points of alligator cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
			Number	Percent			30	20	33	38			
A	1	0 to 2	2482	97	29	**0**	21	56	17	6	8	8	9
B	2	3 to 5	55	2	39	0	**4**	64	18	15	6	7	11
C	3	6 to 10	16	1	42	0	6	**81**	6	6	5	1	9
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									

F	Total	2553	100		0	21	56	17	6	8	8	9

Table 141

A single chipseal treatment transition matrix based on trigger value of 5 deduct points for microsurfacing of transverse cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
						19	13	23	30	32			
A	1	0 to 2	925	100	26	**4**	61	34	1	0	8	4	5
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									

F	Total		925	100		4	61	34	1	0	8	4	5

Table 142

A single chipseal treatment transition matrix based on trigger value of 12.5 deduct points for transverse cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							16	14	25	31			
A	1	0 to 2	890	96	26	**0**	28	48	21	3	8	7	8
B	2	3 to 5	33	4	30	0	**3**	85	6	6	6	5	9
C	3	6 to 10	2	0	32	0	0	**50**	50	0	7	3	11

D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		925	100		0	27	49	21	3	8	7	8

Table 143
A single chipseal treatment transition matrix based on trigger value of 5 deduct points for microsurfacing of longitudinal cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
						20	13	25	30	32			
A	1	0 to 2	642	100	24	**0**	35	56	8	0	9	6	7
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to	0	0									

		25										
F	Total		642	100		0	35	56	8	0	9	6	7

Table 144

A single chipseal treatment transition matrix based on trigger value of 5 deduct points for microsurfacing of longitudinal cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							14	15	26	30			
A	1	0 to 2	615	96	24	**0**	5	48	32	15	9	10	11
B	2	3 to 5	26	4	30	0	**0**	42	50	8	7	7	11
C	3	6 to 10	1	0	32	0	0	**0**	100	0	8	5	13
D	4	11 to 15	0	0									

E	5	16 to 25	0	0									
F	Total		642	100		0	5	48	33	15	9	10	11

Table 145

A single chipseal treatment transition matrix based on IRI trigger value of 20 deduct points for microsurfacing of flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
						3	3	2	2	1			
A	1	0 to 2	862	39	3	**72**	9	10	4	4	3	2	3
B	2	3 to 5	232	10	3	23	**18**	28	17	13	2	4	8
C	3	6 to 10	277	13	2	11	22	**35**	13	18	0	1	9
D	4	11 to 15	209	9	1	8	24	38	**12**	18	-3	-4	9
E	5	16 to 25	634	29	1	5	15	29	16	**35**	-5	-8	12
F	Total		2214	100		34	15	23	11	17	0	-1	8

Table 146

A single chipseal treatment transition matrix based on trigger value of 22.5 deduct points for rut depths in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
						4.36	2.40	5.03	6.56	3.09			
A	1	0 to 2	46	17	9.14	**2**	0	7	4	87	10	18	19
B	2	3 to 5	24	9	7.51	0	**0**	0	8	92	7	15	19
C	3	6 to 10	33	13	3.93	0	0	**0**	3	97	7	12	20
D	4	11 to 15	29	11	3.77	0	3	3	**0**	93	5	6	19
E	5	16 to 25	132	50	4.70	0	1	4	1	**95**	5	-1	19
F	Total		264	100		0	1	3	2	93	6	6	19

Table 147

A single chipseal treatment transition matrix based on trigger value of 5 deduct points for microsurfacing of alligator cracking in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
						34	18	33	39				
A	1	0 to 2	676	100	29	**17**	46	32	5	0	7	4	5
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		676	100		17	46	32	5	0	7	4	5

Table 148
A single chipseal treatment transition matrix based on trigger value of 15 deduct points for alligator cracking in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from the pavement network to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							28	19	33	38			
A	1	0 to 2	668	99	29	**0.00**	25.89	42.01	22.34	8.58	7	8	9
B	2	3 to 5	4	1	38	0.00	**0.00**	0.30	0.30	0.00	6	7	11
C	3	6 to 10	4	1	42	0.00	0.00	**0.30**	0.15	0.15	7	4	12
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		676	100		0	26	43	23	9	7	8	9

Table 149

A single chipseal treatment transition matrix based on trigger value of 5 deduct points for microsurfacing of transverse cracking in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
						17	11	24	30				
A	1	0 to 2	312	100	26	**1**	57	37	5	0	8	5	6
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		312	100		1	57	37	5	0	8	5	6

Table 150

A single chipseal treatment transition matrix based on trigger value of 12.5 deduct points for transverse cracking in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							12	13	25	29			
A	1	0 to 2	310	99	26	**0**	18	49	25	9	8	9	10
B	2	3 to 5	2	1	31	0	**0**	100	0	0	5	4	8
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		312	100		0	18	49	24	9	8	9	10

Table 151

A single chipseal treatment transition matrix based on trigger value of 5 deduct points for microsurfacing of longitudinal cracking in flexible pavements, local roads

<table>
<tr><td rowspan="7">Row designation</td><td colspan="13">Column designation</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>G</td><td>H</td><td>I</td><td>J</td><td>K</td><td>L</td><td>M</td></tr>
<tr><td colspan="13">Condition/distress type: longitudinal cracking</td></tr>
<tr><td colspan="5" rowspan="2">Before treatment (BT) data</td><td colspan="8">After treatment (AT) data</td></tr>
<tr><td colspan="5">RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets</td><td colspan="3">Weighted average treatment life, service life extension, and RSL of the treatment (year)</td></tr>
<tr><td rowspan="2">RSL bracket number</td><td rowspan="2">RSL bracket range (year)</td><td colspan="2">0.1 mile pavement segments</td><td rowspan="2">Average standard error (SE) (ft)</td><td>1
0 to 2</td><td>2
3 to 5</td><td>3
6 to 10</td><td>4
11 to 15</td><td>5
16 to 25</td><td rowspan="2">Treatment life</td><td rowspan="2">Service life extension</td><td rowspan="2">RSL</td></tr>
<tr><td>Number</td><td>Percent</td><td colspan="5">Average SE of each RSL bracket (ft)
17 | 12 | 25 | 30 | 31</td></tr>
<tr><td>A</td><td>1</td><td>0 to 2</td><td>223</td><td>100</td><td>24</td><td>1</td><td>35</td><td>45</td><td>16</td><td>3</td><td>9</td><td>7</td><td>8</td></tr>
<tr><td>B</td><td>2</td><td>3 to 5</td><td>0</td><td>0</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>C</td><td>3</td><td>6 to 10</td><td>0</td><td>0</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>D</td><td>4</td><td>11 to 15</td><td>0</td><td>0</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>E</td><td>5</td><td>16 to 25</td><td>0</td><td>0</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>F</td><td colspan="2">Total</td><td>223</td><td>100</td><td></td><td>1</td><td>35</td><td>45</td><td>16</td><td>3</td><td>9</td><td>7</td><td>8</td></tr>
</table>

Table 152

A single chipseal treatment transition matrix based on trigger value of 12.5 deduct points for longitudinal cracking in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							11	14	26	30			
A	1	0 to 2	223	100	24	**0**	6	39	28	26	9	11	12
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		223	100		0	6	39	28	26	9	11	12

Table 153

A single chipseal treatment transition matrix based on IRI trigger value of 20 deduct points for microsurfacing of flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
						3	2	2	2	1			
A	1	0 to 2	161	34	3	**78**	6	10	2	3	4	2	3
B	2	3 to 5	35	7	1	20	**29**	34	9	9	1	3	7
C	3	6 to 10	65	14	1	8	20	**26**	14	32	-1	3	11
D	4	11 to 15	70	15	1	1	23	36	**21**	19	-3	-3	10
E	5	16 to 25	142	30	1	3	5	29	25	**39**	-5	-7	13
F	Total		473	100		30	12	23	14	21	-1	-1	9

Table 154

A double chipseal treatment transition matrix based on trigger value of 22.5 deduct points for rut depths in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
						5.81	5.12	2.37	2.20	1.97			
A	1	0 to 2	63	26	6.17	**13**	3	3	2	79	9	16	17
B	2	3 to 5	27	11	4.57	0	**0**	4	4	93	9	15	19
C	3	6 to 10	23	9	3.75	0	0	**4**	4	91	8	11	19
D	4	11 to 15	31	13	4.50	0	0	3	**0**	97	8	7	20
E	5	16 to 25	101	41	3.43	4	2	5	5	**84**	3	-2	18
F	Total		245	100		5	2	4	3	86	6	7	18

Table 155
A double chipseal treatment transition matrix based on trigger value of 5 deduct points for alligator cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
						34	18	34	39				
A	1	0 to 2	360	100	30	**16**	52	30	3	0	7	4	5
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		360	100		16	52	30	3	0	7	4	5

Table 156

A double chipseal treatment transition matrix based on trigger value of 15 deduct points for alligator cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							27	18	33	38			
A	1	0 to 2	349	97	30	**0**	26	43	21	9	7	8	9
B	2	3 to 5	8	2	40	0	**50**	50	0	0	4	2	6
C	3	6 to 10	3	1	42	0	100	**0**	0	0	3	-4	4
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		360	100		0	28	43	21	9	7	8	9

Table 157
A double chipseal treatment transition matrix based on trigger value of 5 deduct points for transverse cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
						22	12	27	30				
A	1	0 to 2	94	100	24	**16**	57	21	5	0	7	4	5
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		94	100		16	57	21	5	0	7	4	5

Table 158

A double chipseal treatment transition matrix based on trigger value of 12.5 deduct points for transverse cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							17	11	27	30			
A	1	0 to 2	90	96	24	**0**	41	36	14	9	8	7	8
B	2	3 to 5	4	4	30	0	**25**	50	0	25	5	6	10
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		94	100		0	40	36	14	10	7	7	8

Table 159

A double chipseal treatment transition matrix based on trigger value of 5 deduct points for longitudinal cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							11	25	31				
A	1	0 to 2	61	100	22	**0**	33	62	5	0	9	6	7
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		61	100		0	33	62	5	0	9	6	7

Table 160

A double chipseal treatment transition matrix based on trigger value of 12.5 deduct points for longitudinal cracking in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							12	14	26	31			
A	1	0 to 2	53	87	21	**0**	2	49	32	17	9	11	12
B	2	3 to 5	8	13	30	0	**0**	38	13	50	7	11	15
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		61	100		0	2	48	30	21	9	11	12

Table 161
A double chipseal treatment transition matrix based on IRI trigger value of 20 deduct points in flexible pavements, collector roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
						3	2	2	1	1			
A	1	0 to 2	259	59	3	**66**	9	8	6	10	4	4	5
B	2	3 to 5	26	6	1	19	**42**	15	15	8	0	3	7
C	3	6 to 10	33	8	1	12	30	**36**	15	6	0	-1	7
D	4	11 to 15	22	5	1	18	9	41	**18**	14	-3	-4	9
E	5	16 to 25	96	22	1	0	14	36	21	**29**	-5	-8	12
F	Total		436	100		42	14	19	11	14	1	0	7

Table 162

A double chipseal treatment transition matrix based on trigger value of 22.5 deduct points for rut depths in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from the pavement network to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
						2.56	3.51	2.25	2.54	2.42			
A	1	0 to 2	58	52	6.51	**0.89**	3.57	1.79	3.57	41.96	9	17	18
B	2	3 to 5	8	7	5.04	0.00	**2.68**	0.00	0.00	4.46	6	10	14
C	3	6 to 10	6	5	3.34	0.00	0.89	**0.00**	0.00	4.46	7	9	17
D	4	11 to 15	17	15	4.61	0.00	0.89	0.89	**0.00**	13.39	6	5	18
E	5	16 to 25	23	21	5.55	0.00	7.14	0.00	1.79	**11.61**	5	-6	14
F	Total		112	100		1	15	3	5	76	8	9	17

Table 163
A double chipseal treatment transition matrix based on trigger value of 5 deduct points for microsurfacing of alligator cracking in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
						37	19	31					
A	1	0 to 2	127	100	31	**17**	59	24	0	0	8	3	4
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		127	100		17	59	24	0	0	8	3	4

Table 164

A double chipseal treatment transition matrix based on trigger value of 15 deduct points for alligator cracking in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: alligator cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							30	20	32	40			
A	1	0 to 2	121	95	31	**0**	31	52	16	1	8	7	8
B	2	3 to 5	2	2	36	0	**50**	50	0	0	4	2	6
C	3	6 to 10	4	3	43	0	0	**100**	0	0	5	0	8
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		127	100		0	31	54	15	1	8	6	8

Table 165
A double chipseal treatment transition matrix based on trigger value of 5 deduct points for microsurfacing of transverse cracking in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: transverse cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							11	24					
A	1	0 to 2	9	100	19	**0**	56	44	0	0	10	5	6
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		9	100		0	56	44	0	0	10	5	6

Table 166

A double chipseal treatment transition matrix based on trigger value of 12.5 deduct points for transverse cracking in flexible pavements, local roads

<table>
<tr><td rowspan="9">Row designation</td><td colspan="13">Column designation</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>G</td><td>H</td><td>I</td><td>J</td><td>K</td><td>L</td><td>M</td></tr>
<tr><td colspan="13">Condition/distress type: transverse cracking</td></tr>
<tr><td colspan="5" rowspan="2">Before treatment (BT) data</td><td colspan="8">After treatment (AT) data</td></tr>
<tr><td colspan="5">RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets</td><td colspan="3">Weighted average treatment life, service life extension, and RSL of the treatment (year)</td></tr>
<tr><td rowspan="4">RSL bracket number</td><td rowspan="4">RSL bracket range (year)</td><td colspan="2" rowspan="2">0.1 mile pavement segments</td><td rowspan="4">Average standard error (SE) (ft)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td rowspan="4">Treatment life</td><td rowspan="4">Service life extension</td><td rowspan="4">RSL</td></tr>
<tr><td>0 to 2</td><td>3 to 5</td><td>6 to 10</td><td>11 to 15</td><td>16 to 25</td></tr>
<tr><td rowspan="2">Number</td><td rowspan="2">Percent</td><td colspan="5">Average SE of each RSL bracket (ft)</td></tr>
<tr><td></td><td></td><td>13</td><td>25</td><td></td></tr>
<tr><td>A</td><td>1</td><td>0 to 2</td><td>9</td><td>100</td><td>19</td><td>0</td><td>0</td><td>67</td><td>33</td><td>0</td><td>10</td><td>9</td><td>10</td></tr>
<tr><td>B</td><td>2</td><td>3 to 5</td><td>0</td><td>0</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>C</td><td>3</td><td>6 to 10</td><td>0</td><td>0</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>D</td><td>4</td><td>11 to 15</td><td>0</td><td>0</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>E</td><td>5</td><td>16 to 25</td><td>0</td><td>0</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>F</td><td colspan="2">Total</td><td>9</td><td>100</td><td></td><td>0</td><td>0</td><td>67</td><td>33</td><td>0</td><td>10</td><td>9</td><td>10</td></tr>
</table>

Table 167

A double chipseal treatment transition matrix based on trigger value of 5 deduct points for microsurfacing of longitudinal cracking in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (ft)							
							14	25	29				
A	1	0 to 2	30	100	22	**0**	50	47	3	0	10	5	6
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		30	100		0	50	47	3	0	10	5	6

Table 168

A double chipseal treatment transition matrix based on trigger value of 12.5 deduct points for longitudinal cracking in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: longitudinal cracking												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (ft)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (ft)							
							17	15	27	30			
A	1	0 to 2	30	100	22	**0**	3	63	20	13	10	9	10
B	2	3 to 5	0	0									
C	3	6 to 10	0	0									
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		30	100		0	3	63	20	13	10	9	10

Table 169

A double chipseal treatment transition matrix based on IRI trigger value of 20 deduct points in flexible pavements, local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in/mi)							
						3	3	2	1	1			
A	1	0 to 2	73	55	3	**85**	11	4	0	0	2	1	2
B	2	3 to 5	10	8	1	30	**50**	10	10	0	1	0	4
C	3	6 to 10	9	7	1	11	56	**0**	0	33	-1	1	9
D	4	11 to 15	16	12	1	13	31	25	**13**	19	-4	-4	9
E	5	16 to 25	25	19	1	0	4	68	12	**16**	-6	-10	10
F	Total		133	100		51	18	19	5	8	0	-2	5

Table 170
A triple chipseal treatment transition matrix based on trigger value of 22.5 deduct points for rut depths in flexible pavements, collector and local roads

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: rut depth												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in)	1	2	3	4	5	Treatment life	Service life extension	RSL
						0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
			Number	Percent		Average SE of each RSL bracket (in)							
						11.97	8.19	3.93	4.72	6.67			
A	1	0 to 2	20	51	4.17	**30**	15	15	10	30	8	8	9
B	2	3 to 5	2	5	5.16	0	**0**	0	50	50	9	13	17
C	3	6 to 10	3	8	6.06	33	33	**0**	33	0	2	-2	6
D	4	11 to 15	1	3	1.91	0	0	0	**0**	100	10	7	20
E	5	16 to 25	13	33	3.28	0	8	0	15	**77**	5	-2	18
F	Total		39	100		18	13	8	15	46	7	4	13

Table 171

A triple chipseal treatment transition matrix based on IRI trigger value of 20 deduct points in flexible pavements, collector and local roads (No significant number for alligator, transverse, and longitudinal)

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: IRI												
	Before treatment (BT) data					After treatment (AT) data							
						RSL bracket number and range in years, the average standard error per RSL bracket, and the percent of the 0.1 mile pavement segments transferred from each BT RSL bracket to the indicated RSL brackets					Weighted average treatment life, service life extension, and RSL of the treatment (year)		
	RSL bracket number	RSL bracket range (year)	0.1 mile pavement segments		Average standard error (SE) (in/mi)	1	2	3	4	5	Treatment life	Service life extension	RSL
			Number	Percent		0 to 2	3 to 5	6 to 10	11 to 15	16 to 25			
						Average SE of each RSL bracket (in/mi)							
						3	3	1	3				
A	1	0 to 2	22	81	3	**86**	9	5	0	0	6	1	2
B	2	3 to 5	3	11	3	33	**33**	0	33	0	0	2	6
C	3	6 to 10	2	7	6	0	100	**0**	0	0	2	-4	4
D	4	11 to 15	0	0									
E	5	16 to 25	0	0									
F	Total		27	100		74	19	4	4	0	5	0	2

Reset Values of Treatments

Based on the methodology described earlier, reset values of treatments for flexible and composite pavements are shown in Table 173 through Table 184. Resets are presented against actual distress values in Table 173 through Table 178 and against index values in Table 179 through Table 184. In some functional classifications, few projects were available for analysis, which made the results statistically insignificant. It is recommend that only those reset values must be utilized that were obtained using five or more projects.

Table 172
Reset values for flexible pavement with HMA overlay treatments based on actual distress value

Flexible Resets for Overlay										
Functional Classification	Thickness	IRI (in/mile)					RUT(in)	Alligator (Sq ft)	Longitudinal (ft)	Transverse (ft)
		Max	Min	Average	Standard Deviation	No. of Projects				
Interstate	2"	58	45	49.30	7.18	3*	0	0	0	0
	3.5"	-	-	-	-	0	0	0	0	0
	>4"	-	-	-	-	0	0	0	0	0
Arterial	2"	94	52	66.80	15.15	8	0	0	0	0
	3.5"	78	35	57.40	11.68	18	0	0	0	0
	>4"(only 5")	70	60	65.60	6.44	2*	0	0	0	0
Collector	2"	99	49	72.80	13.33	19	0	0	0	0
	3.5"	91	39	59.20	11.10	62	0	0	0	0
	>4"(4.5" to 6")	101	51	68.90	17.04	9	0	0	0	0
Local	2"	-	-	-	-	0	0	0	0	0
	3.5"	94	41	59.60	12.20	25	0	0	0	0
	>4"(only 4.5)	64	64	64.40	-	1*	0	0	0	0

* Not recommended (less than 5 projects).

Table 173

Reset values for flexible pavement with chipseal treatments based on actual distress value

Flexible Resets for Chipseal																	
Functional Classification	IRI (in/mile)							RUT (in)							Alligator (Sq ft)	Long (ft)	Trans (ft)
	Max	Min	Avg	Std Dev.	No. of Projects	Equation	R^2	Max	Min	Avg	Std Dev.	No. of Projects	Equation	R^2			
Interstate	-	-	-	-	0	-	-	-	-	-	-	0	-	-	0	0	0
Arterial	-	-	-	-	0	-	-	-	-	-	-	0	-	-	0	0	0
Collector	236	70	126	37.4	97	IRI(Reset) = 0.811IRIp+ 24.29	0.89	0.6	0.06	0.2	0.08	96	Rut(Reset) = 0.643*RUTp+0.079	0.38	0	0	0
Local	265	78	144	55.1	44	IRI(Reset) = 0.844IRIp+ 22.18	0.93	0.5	0.08	0.2	0.09	38	Rut(Reset) = 0.747*RUTp+0.092	0.39	0	0	0

* Not recommended (less than 5 projects).

Table 174

Reset values for flexible pavement with Microsurfacing treatments based on actual distress value

Flexible Resets for Micro Surfacing																	
Functional Classification	IRI (in/mile)							RUT (in)							Alligator (Sq ft)	Long (ft)	Trans (ft)
	Max	Min	Avg	Std. Deviation	No. of Projects	Eq	R-sq	Max	Min	Avg	St. Deviation	No. of Projects	Equation	R-sq			
Interstate	-	-	-	-	0	-	-	-	-	-	-	0	-	-	0	0	0
Arterial	74	74	74	-	1*	-	-	0.19	0.13	0.16	0.040	2*	-	-	0	0	0
Collector	135	72	100	25.9	5	IRI(Reset) equals 1.101IRIp-17.44	0.6	0.11	0.09	0.10	0.003	3*	-	-	0	0	0
Local	221	200	211	14.9	2*	-	-	0.1	0.1	0.1	-	1*	-	-	0	0	0

* Not recommended (less than 5 projects).

Table 175

Reset values for composite pavement with HMA overlay treatments based on actual distress value

Composite Resets for Overlay										
Functional Classification	Thickness	IRI (in/mile)					RUT(in)	Alligator (Sq ft)	Longitudinal (ft)	Transverse (ft)
		Max	Min	Average	St. Deviation	No. of Projects				
Interstate	2"	66	66	66	-	1*	0	0	0	0
	3.5"	36	36	36	-	1*	0	0	0	0
	4"	44	34	39	4.4	5	0	0	0	0
Arterial	2"	202	50	93.8	43.2	16	0	0	0	0
	3.5"	175	44.6	76.9	34.1	16	0	0	0	0
	> equals 4"	149	41.6	79.4	29.6	16	0	0	0	0
Collector	2"	79	46.9	63.1	22.9	2*	0	0	0	0
	3.5"	123	52.3	69.4	20.9	9	0	0	0	0
	> equals 4"	-	-	-	-	-	0	0	0	0
Local	2"	-	-	-	-	-	0	0	0	0
	3.5"	-	-	-	-	-	0	0	0	0
	> equals 4"	-	-	-	-	-	0	0	0	0

* Not recommended (less than 5 projects).

Table 176
Reset values for composite pavement with chipseal treatments based on actual distress value

Composite Resets for Chipseal															
Functional Classification	IRI (in/mile)					RUT (in)							Alligator (Sq ft)	Long (ft)	Trans (ft)
	Max	Min	Avg	Std. Deviation	No. of Projects	Max	Min	Avg	Std. Deviation	No. of Projects	Equation	R-sq			
Interstate	45	45	45	-	1*	-	-	-	-	0	-	-	0	0	0
Arterial	104	104	104	-	1*	0.22	0.12	0.16	0.05	3*	-	-	0	0	0
Collector	192	58	137	34.3	11	0.38	0.11	0.24	0.08	10	Rut(Reset) equals 0.66 * Rutp +0.052	0.70	0	0	0
Local	106	97	101	6.3	2*	0.22	0.19	0.20	0.02	2*	-	-	0	0	0

* Not recommended (less than 5 projects).

Table 177

Reset values for composite pavement with Microsurfacing treatments based on actual distress value

Composite Resets for Micro Surfacing													
Functional Classification	IRI (in/mile)					RUT (in/mile)					Alligator (Sq ft)	Long (ft)	Trans (ft)
	Max	Min	Avg	Std. Deviation	No. of Projects	Max	Min	Average	Std. Deviation	No. of Projects			
Arterial	165	69	116.9	67.96	2*	0.38	0.10	0.24	0.20	2*	0	0	0

* Not recommended (less than 5 projects).

Table 178
Reset values for flexible pavement with HMA overlay treatments based on index value

Flexible Resets for Overlay									
Functional Classification	Thickness	Roughness Index				RUT Index	Alligator Index	Longitudinal Index	Transverse Index
		Min	Max	Average	No. of Projects				
Interstate	2"	98	100	100.00	3*	100	100	100	100
	3.5"				0	100	100	100	100
	>4"				0	100	100	100	100
Arterial	2"	91	100	96.6	8	100	100	100	100
	3.5"	94	100	98.5	18	100	100	100	100
	>4"(only 5")	96	98	96.9	2*	100	100	100	100
Collector	2"	90	100	95.4	19	100	100	100	100
	3.5"	92	100	98.2	62	100	100	100	100
	>4"(4.5" to 6")	90	100	96.2	9	100	100	100	100
Local	2"				0	100	100	100	100
	3.5"	91	100	98.1	25	100	100	100	100
	>4"(only 4.5)	97	97	97.1	1*	100	100	100	100

* Not recommended (less than 5 projects).

Table 179
Reset values for flexible pavement with chipseal treatments based on index value

Flexible Resets for Chipseal												
Functional Classification	Roughness Index				RUT Index				Alligator Index	Longitudinal Index	Transverse Index
	Min	Max	Avg	Std. Deviation	Min	Max	Avg	No. of Projects			
Interstate	-	-	-	-	-	-	-	0	100	100	100
Arterial	-	-	-	-	-	-	-	0	100	100	100
Collector	63	96	84.8	-	64	100	94.1	96	100	100	100
Local	57	94	81.16	-	67	100	95.2	38	100	100	100

Table 180
Reset values for flexible pavement with Microsurfacing treatments based on index value

Flexible Resets for Micro Surfacing											
Functional Classification	Roughness Index				RUT Index				Alligator Index	Longitudinal Index	Transverse Index
	Min	Max	Average	No. of Projects	Min	Max	Average	No. of Projects			
Interstate	-	-	-	0	-	-	-	0	100	100	100
Arterial	95	95	95.21	1*	95	100	97.28	2*	100	100	100
Collector	83	96	90.01	5	100	100	100	3*	100	100	100
Local	66	70	67.85	2*	100	100	100	1*	100	100	100

* Not recommended (less than 5 projects).

Table 181
Reset values for composite pavement with HMA overlay treatments based on index value

Composite Resets for Overlay									
Functional Classification	Thickness	Roughness Index				RUT Index	Alligator Index	Longitudinal Index	Transverse Index
		Min	Max	Average	No. of Projects				
Interstate	2"	97	97	97	1*	100	100	100	100
	3.5"	100	100	100	1*	100	100	100	100
	4"	100	100	100	5	100	100	100	100
Arterial	2"	70	100	91.2	16	100	100	100	100
	3.5"	75	100	94.6	16	100	100	100	100
	> equals 4"	80	100	94.1	16	100	100	100	100
Collector	2"	94	100	97.4	2*	100	100	100	100
	3.5"	85	100	96.1	9	100	100	100	100
	> equals 4"	-	-	-	-	100	100	100	100
Local	2"	-	-	-	-	100	100	100	100
	3.5"	-	-	-	-	100	100	100	100
	> equals 4"	-	-	-	-	100	100	100	100

* Not recommended (less than 5 projects).

Table 182
Reset values for composite pavement with chipseal treatments based on index value

Composite Resets for Chipseal											
Functional Classification	Roughness Index				Rut Index				Alligator Index	Longitudinal Index	Transverse Index
	Min	Max	Average	No. of Projects	Min	Max	Average	No. of Projects			
Interstate	100	100	100	1*	-	-	-	0	100	100	100
Arterial	89	89	89	1*	92	100	96.78	3*	100	100	100
Collector	72	98	82.7	11	79	100	90.77	10	100	100	100
Local	89	91	89.8	2*	93	95	93.81	2*	100	100	100

* Not recommended (less than 5 projects).

Table 183

Reset values for composite pavement with Microsurfacing treatments based on index value

Composite Resets for Micro Surfacing											
Functional Classification	Roughness Index				RUT Index				Alligator Index	Longitudinal Index	Transverse Index
	Min	Max	Average	No. of Projects	Min	Max	Average	No. of Projects			
Arterial	77	96	86.62	2*	79	100	90.75	2*	100	100	100

* Not recommended (less than 5 projects).

Summary of Treatment Life

Treatment life is defined as the estimated time in years between the treatment year and the year when the AT pavement conditions or distresses reach the lesser of the threshold value or the BT pavement condition or distress as shown in Figure 41. For each 1/10th miles pavement segment along the project, T^2M was used and treatment life was calculated based on controlling distress. Table 185 and Table 186 represent calculated treatment life of overlay and chipseal treatment for flexible and composite pavements. Microsurfacing treatment on flexible pavement yields a treatment life of 5.5 years with a standard deviation of 3.0 year based on 263 1/ 10th mile pavement segments for all classifications.

Table 184
Treatment life of overlay treatment for flexible pavement and composite pavement

Overlay Treatment							
Thickness of Overlay	Flexible Pavement				Composite Pavement		
	Functional Classification	Average Treatment Life (years)	Standard Deviation	No. of Data Points	Average Treatment Life (years)	Standard Deviation	No. of Data Points
2"	Interstate	11.0	3.8	53	-	-	-
	Arterial	9.0	3.8	123	8.0	3.8	334
	Collector	8.0	3.9	505	7.0	4.1	193
	Local	6.5	3.0	25	-	-	-
3.5"	Interstate	8.5	3.5	51	6.0	1.1	105
	Arterial	9.5	4.6	496	8.0	3.6	186
	Collector	7.5	3.6	1783	6.0	3.6	60
	Local	6.5	3.2	445	-	-	-
>4"	Interstate	-	-	-	-	-	-
	Arterial	13.5	3.3	83	10.0	3.8	36
	Collector	8.5	3.7	186	-	-	-
	Local	10.0	3.7	151	-	-	-

Table 185
Treatment life of chipseal treatment for flexible pavement and composite pavement

Chipseal Treatment							
Application Type		Flexible Pavement			Composite Pavements		
	Functional Classification	Average Treatment Life (years)	Standard Deviation	No. of Data Points	Average Treatment Life (years)	Standard Deviation	No. of Data Points
Single	Interstate	-	-	-	9.5	2.8	44
	Arterial	-	-	-	6.0	2.3	88
	Collector	6.0	3.1	3946	5.5	4.7	313
	Local	6.5	2.7	1085	4.0	1.8	29
Double	Interstate	-	-	-	-	-	-
	Arterial	-	-	-	-	-	-
	Collector	6.0	3.5	766	4.0	3.3	26
	Local	6.0	3.1	201	-	-	-

Treatment Cost Benefit Analysis (TCBA)

The aim of TCBA is to develop guidelines for the implementation of cost-effective pavement preservation strategies that would maximize the user and agency benefits and minimize their costs. For the purpose of Illustrating TCBA approach, a project 001-03-0067 is considered. The project is in route US79 in district 4. Under this project in control section 001-03-1, 2 in. HMA overlay treatment was done in 2001. There is available pavement distress data till 2008, and the pavement engineer wants to plan ahead and select future treatments based on TCBA.

Table 186
Distress values used in TCBA illustration

Year of Distress data collection	Time (after treatment at year 2001)	Distress Value				
		IRI (in/mile)	Transverse Crack (ft/mile)	Longitudinal Crack (ft/mile)	Fatigue Crack (ft/mile)	Rut (in)
2003	2	98.1	633.0	249.5		0.11
2004	3	106.7	905.9			0.13
2006	5	114.7	1718.7	948.1		0.14
2008	7	124.9	3941.6	1917.5		0.15

Pavement performance models are applied to the existing condition of the pavement and performances are predicted for future. Reviewing all the actual distress value, it is evident that transverse crack is pretty dominant in the pavement and it is acting as the controlling distress. As the controlling distress already exceeded the trigger values of applying chipseal and microsurfacing treatment as of eight year since the application of overlay at 2001, the remaining option is applying HMA overlay treatment.

A 2-in HMA overlay treatment is selected as the treatment to apply in the pavement at year 2009, eight years after the first treatment. All the distresses revert to their reset values after the application of treatment. Again, the performance models are used to predict the behavior of pavement. This time pavement engineer wants to apply chipseal treatment. Trigger value for 2-

application chipseal treatment is reached by both transverse crack and longitudinal crack at the year 13. So, at year 13, 2-application chipseal is applied at the pavement and from that time the performance models are used to see when the pavement will reach its threshold value.

From the performance models it is found that transverse crack will reach its threshold value at year 18 from the first treatment. So, the benefits will be experienced by the pavement for these two treatments till 2019. To get the benefit experienced by the pavement for these two treatments, individual benefit area is calculated for each distress. The area will be calculated using discrete area method as described in the methodology.

Table 187
Benefits calculated from performance models

Benefit Type	Normalized Benefit Area					Total Normalized Benefit Area
	IRI	TC	LC	FC	Rut	
Do Nothing	1.605	0.000	0.033	0.238	4.208	6.083
Treatment 1 (HMA Overlay 2-in)	2.218	3.931	4.171	7.613	1.458	19.391
Treatment 2 (2-Application Chipseal)	0.671	3.125	4.450	2.046	0.837	11.129

The cost will be calculated based on current year. That means year 7 will act as year zero for cost calculating formulas. Figure 117 has demonstration for cost calculation.

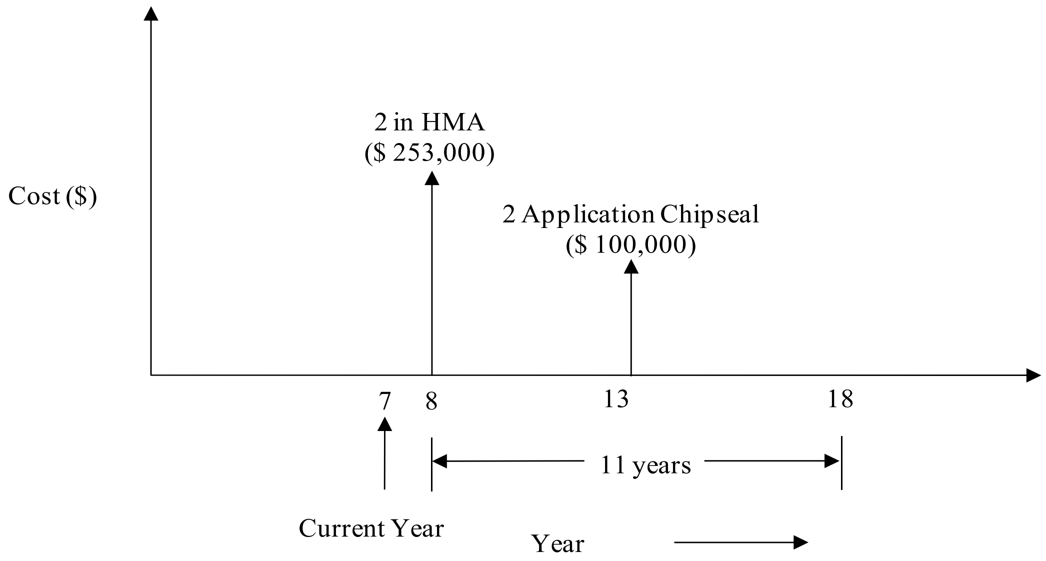


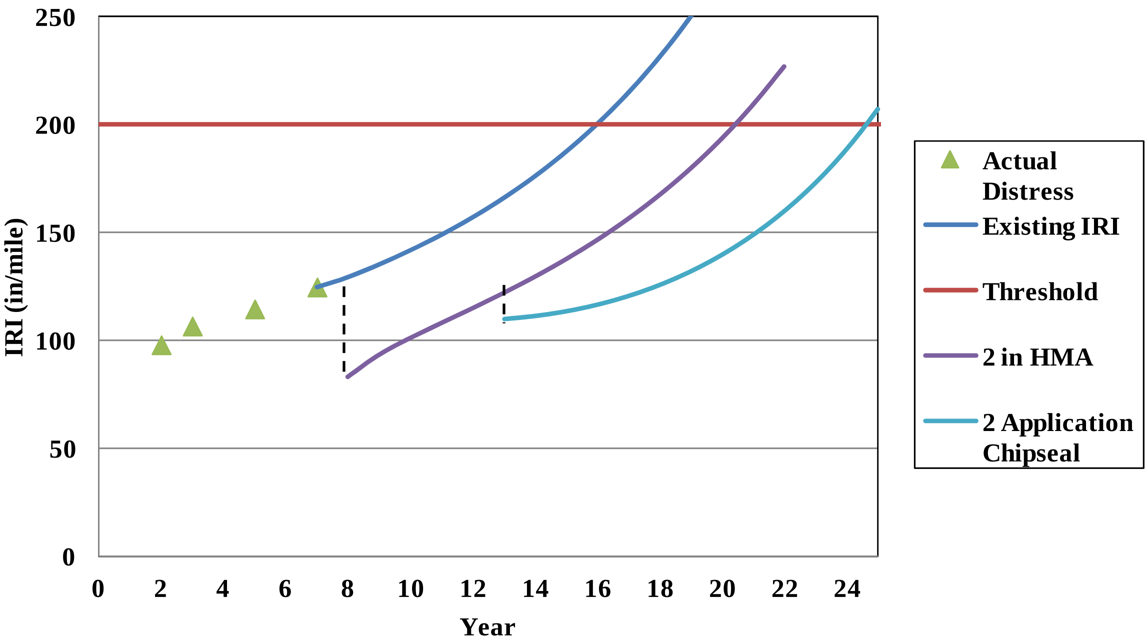
Figure 117
Cost calculation for TCBA analysis

The cost benefit ratio using the procedure described in the methodology and the results are shown in Table 189.

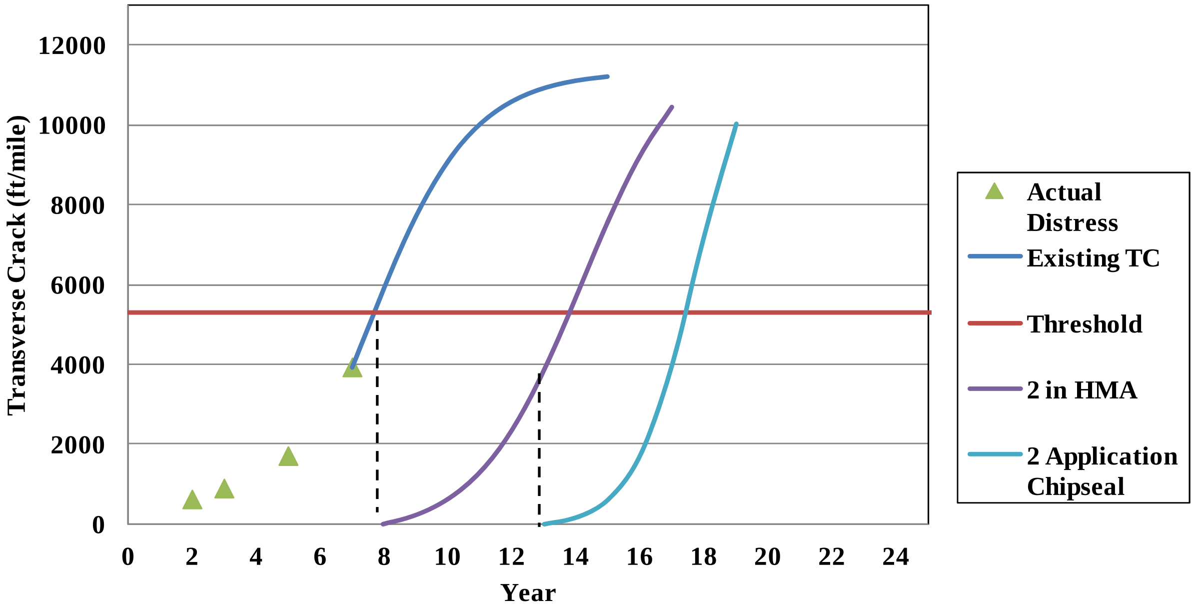
Table 188

Benefit and costs of various alternatives

Treatments	Benefit Area	Current Year	Application Year	Cost ($)	Discounted Cost ($)	Cost Benefit Ratio	Life (Controlling Distress)	Total Cost Benefit Ratio	Total Cost Benefit Ratio Per Year
Treatment 1 (2 in HMA)	19.39	7	8	$253,000	$243,269	12,546	11	19,647	1,786
Treatment 2 (chipseal)	11.13	7	13	$100,000	$79,031	7,102			



(a)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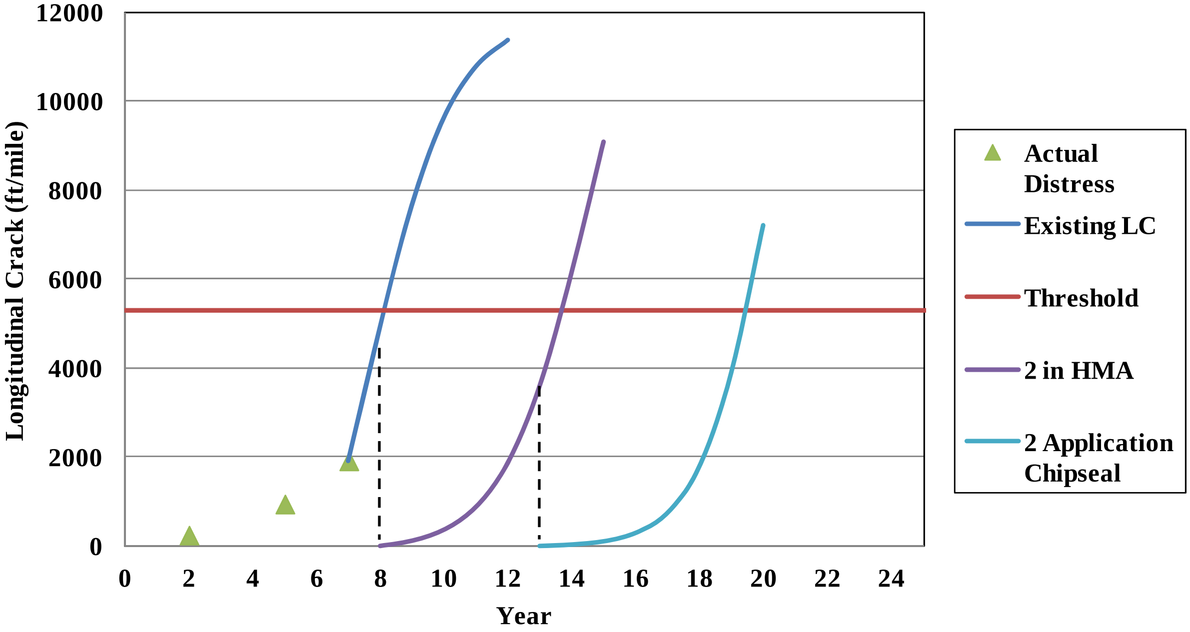
10000
8000
6000
4000
2000
0
Transverse Crack (ft/mile)
0
2
4
6
8
10
12
14
16
18
20
22
24
Year
Actual Distress
Existing TC
Threshold
2 in HMA
2 Application Chipseal

(b)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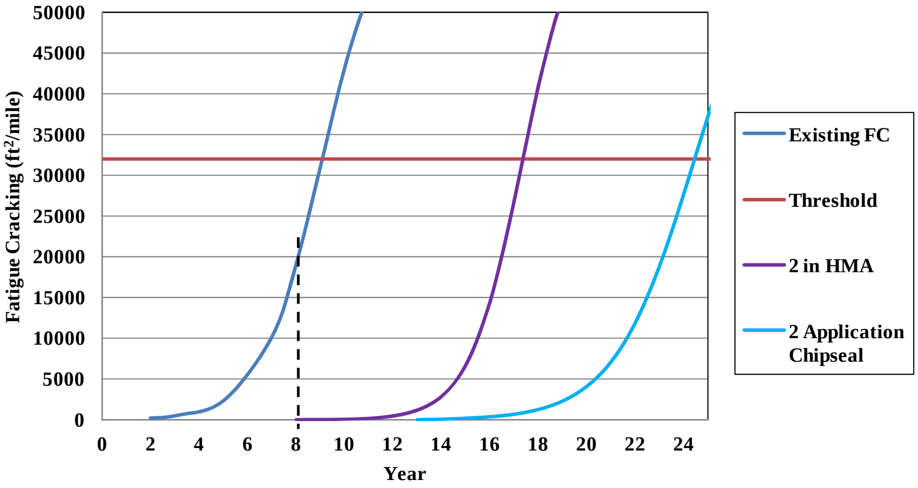
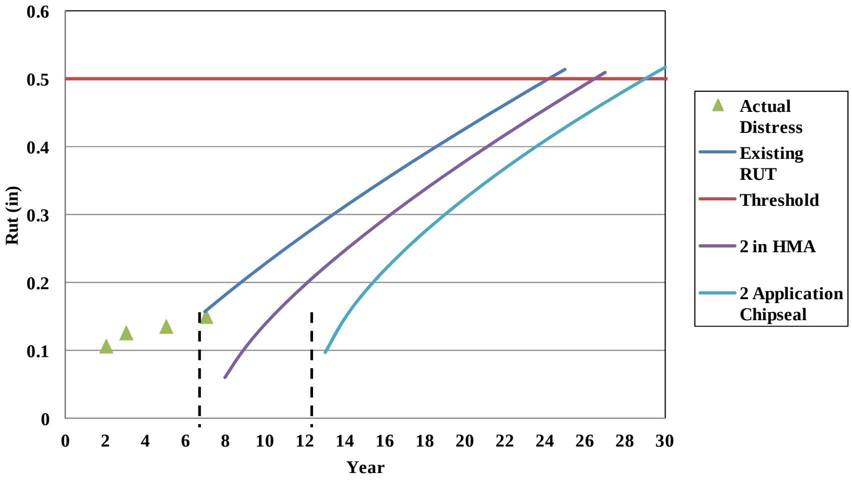
10000
8000
6000
4000
2000
0
Longitudinal Crack (ft/mile)
0
2
4
6
8
10
12
14
16
18
20
22
24
Year
Actual Distress
Existing LC
Threshold
2 in HMA
2 Application Chipseal

(c)



(d)



(e)

Figure 118

Performance of control section 001-03-1 for application of 2 in. HMA overlay and chipseal treatments.

All the possible treatment options analyzed for the pavement and shown in Table 190 are ranked by cost benefit ratio/ year. From the table, it can be seen that the lowest cost-benefit ratio/year is achieved by treatment 1 (2-in. HMA overlay) and treatment 2 (chipseal) combination.

Table 1890

Cost benefit ratio for possible treatments alternatives for control section 001-03-1.

Alternatives	Treatments	Benefit Area	Current Year	Application Year	Cost	Discounted Cost	Cost Benefit Ratio	Life (Controlling distress)	Total Cost Benefit Ratio	Total Cost Benefit Ratio/ Year	Rank
1	Treatment 1 (2 in HMA)	18.72	7	8	$253,000	$243,269	12996	18	20097	1117	1
	Treatment 2 (chipseal)	11.13	7	13	$100,000	$79,031	7102				
2	Treatment 1 (4 in HMA)	24.36	7	8	506,000	$486,538	19973	19	27605	1453	4
	Treatment 2 (chipseal)	9.96	7	14	100000	$75,992	7632				
3	Treatment 1 (4 in HMA)	25.08	7	8	506,000	$486,538	19400	20	34886	1744	5
	Treatment 2 (2 in HMA)	12.42	7	14	253,000	$192,259	15486				
4	Treatment 1 (2 in HMA)	19.48	7	8	253,000	243,269	12487	20	35307	1765	6
	Treatment 2 (4 in HMA)	17.52	7	13	506,000	399,899	22821				
5	Treatment 1 (2 in HMA)	18.1	7	8	253,000	$243,269	13437	17	19326	1137	2
	Treatment 2 (Microsurfacing)	6.98	7	12	50000	$41,096	5888				
6	Treatment 1 (4 in HMA)	23.45	7	8	506,000	$486,538	20752	18	26068	1448	3
	Treatment 2 (Microsurfacing)	7.43	7	13	50000	$39,516	5316				

CONCLUSIONS

Based on the analysis of the responses of six districts to the survey questionnaire, thorough data mining, and the outcomes of comprehensive data analyses, the following conclusions were drawn:

District Surveys and Data Mining

- The pavement design practices are consistent amongst the various districts.
- The state -of-the-practice regarding project scoping process, pavement evaluation, and treatment type selection varies substantially from one district to another and in most cases, it is not compatible with the established trigger values for treatments.
- In general, the pavement conditions and the controlling distress/condition before and after treatment vary from one district to another.
- The pavement surface distress and conditions along projects selected for treatment are highly variable.
- The PMS databank is missing some critical data elements. These include layer thicknesses, traffic, detailed costs, material properties and so forth. During the study, substantial time was spent by the DOTD staff and members of the research team in collecting such data.
- The pavement treatment trigger values used by the districts vary from one district to the next.
- Life-Cycle Cost Analysis (LCCA) is not used by any district in their decision making process. Nowadays, LCCA and the estimated treatment benefits are used by many states to arrive at cost-effective decisions.
- Sufficient projects with adequate time dependent pavement performance data were available for overlays, chipseal, and replacement treatments, with good history and performance data but statistically insignificant number of fewer projects with adequate time dependent pavement performance data were found in the DOTD database for other treatment types.

Treatment Performance Models and Treatment Cost Benefits Analysis

- Time dependent pavement performance prediction models were developed for IRI, rut depth, fatigue, longitudinal, and transverse cracking that simulate the measured data very well.

- The newly developed temperature and precipitation indices showed strong statistical significance for predicting pavement distresses. The indices along with other variables were incorporated into the pavement performance prediction models.
- The developed treatment performance models for each distress were largely affected by the highway functional classification, cumulative ESAL, thickness of the pavement, temperature and precipitation.
- For some distress types, the after treatment pavement performance models are a function of the before treatment pavement condition
- A methodology for the selection of the treatment was developed. The treatment cost benefit analysis (TCBA) is based on a) the benefits of each treatment estimated by the area under the performance curve; and b) costs including agency and user costs along with the salvage value. The TCBA is applicable to various combinations of multiple treatments.

Calibration of Treatment Triggers, Resets, and Deduct Values

- Treatment transition matrices (T^2M) were developed based on the before and after treatment remaining service life (RSL), which was estimated using the time dependent deduct points and distress data. The matrices also include three estimates of the treatment benefits; treatment life (TL), service life extension (SLE) and the RSL.
- The T^2M analyses were found to be a valuable tool for evaluating the effectiveness of pavement treatments, the time of treatment and the trigger values.
- In general, the time dependent sensor collected data (rut depth and IRI) are much more consistent from one data collection cycle to the next than the image collected data (distress). Hence, much more sensor data can be modeled than distress data.
- Detailed time dependent pavement performance data are available in the DOTD database. However, the cost data are available in a summary format only. Such data address the total cost of the entire pavement project and its associated work plan, not the treatment cost alone.
- Due to the lack of detailed cost data along the pavement projects, the calibration of the trigger values was accomplished based on the pavement performance data along the project only. The performance data were obtained from the DOTD database.

- For a given treatment type and road class, the before and after treatment distribution of the pavement conditions and distress along one project is highly variable but more or less similar between projects receiving the same treatment type.
- Based on the results of the before and after treatment pavement performance and treatment benefits analyses listed in the T2M, the DOTD treatment trigger and reset values were calibrated for each road class and distress, treatment, and pavement types.
- The deduct points for roughness index and rut index are reasonable and consistent with the state -of-the-practice in pavement construction. On the other hand, the deduct points for low, medium, and high severity cracking are not consistent and in several scenarios, are not compatible with the severity and extent of the cracking.
- It is shown that the calculation of deduct points based on severity levels of the pavement distress causes errors in the calculated deduct points. Such errors are minimized if the calculation of the deduct points is based on the sum of the crack lengths or areas of all severity levels.
- Calibration of deducts points for cracking were based on two approaches. One was based on cracks with low, medium and high severity levels and the second utilized the concept of the summations of cracks with all severity levels, as is in-line with MEPDG. Two sets of deduct point models based on the above two approaches were developed, which produced results that were consistent and coherent with the existing state -of-the-practice of the DOTD.

RECOMMENDATIONS

Based on the results of the data analyses and the various issues addressed in this study, findings, the following recommendations are made:

- Meetings and special discussion sessions frequently held between the districts personnel to share learned experience and to enhance the intra communication channel. This may lead to a more uniform pavement treatment practices.
- All costs and other pavement treatment project related data should be integrated into the PMS database for easy access. This would assist the department engineers and staff to access the data easily and to enhance the intra communication channel.
- Since the pavement distress and condition vary considerably from one 0.1 mile long pavement segment to the next along a given project, the actual costs would also vary. It is highly recommended that the DOTD requires the contractor to include in the invoice the treatment costs of each 0.1 mile long pavement segment. The data should be kept in the database and used in future study to re-calibrate the treatment trigger values based on maximizing the benefits to cost ratio.
- It is strongly recommended that the image data digitization process be improved by training the data digitizer and by establishing a stricter quality control/ quality assurance processes.
- It is strongly recommended that the proposed deduct point systems and the newly calibrated trigger values be adopted and implemented as soon as possible. These values can be used for the selection of treatment type and time and project boundaries.
- It is strongly recommended that the newly calibrated trigger values be published using two terminologies, the actual value of the distress and the associated deduct points. This should assist the DOTD staff to relate deduct points to distress values.
- It is strongly recommended that the newly developed pavement prediction models, the new deduct point systems, and the calibrated trigger values be periodically visited, verified and re-calibrated as more pavement performance and cost data become available.
- Due to lack of data some of the treatment performance models used either cumulative ESAL or time variables only. Such models need to be further modified to incorporate thickness, functional classification, temperature and precipitation indices, once additional data is available.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ARAN	Automated road analyzer
ASP	Flexible pavements
COM	Composite pavements
CRC	Continuously reinforced concrete pavements
FHWA	Federal Highway Administration
IHS	Interstate highway system
IRI	International roughness index
JCP	Jointed Concrete Pavement
DOTD	Louisiana Department of Transportation and Development
LETS	Letting of projects
LTRC	Louisiana Transportation Research Center
LTPP	Long Term Pavement Performance
MATS	Material Testing System
NHS	National Highway System
PMS	Pavement Management System
PRC	Project Review Committee
RHS	Regional Highway System
RSL	Remaining service life
SHA	State highway agencies
SHS	State highway system
TOPS	Tracking of projects

REFERENCES

1. Baladi, G Y, Novak, E. C. and Kuo, W. *Pavement condition index - remaining service life.* Atlantic City, New Jersey Pavement Management Implementation symposium, 1992.
2. Azpuru, M. and Ramos, K. Dos. *A Comparison of Spatial Interpolation Methods for Estimation of Average Electromagnic Filed Magnitude.* Progress In Electromagnetics Research M, Vol. Vol. 14, pp. 135-145, 2010.
3. ARA, .Inc., ERES Division. *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. Chapter 4-Design of New and Reconstructed Rigid Pavements.* Champaign, Illinois National Cooperative Highway Research Program, 2001.
4. George, K. P. *MDOT Pavement Management System: Prediction Models and Feedback System.* Jackson, MS 39215-1850 Mississippi Department of Transportation, 2000.
5. Jackson, N. and Puccinelli, J. *Long-Term Pavement Performance (LTPP) Data Analysis Support National Pooled Fund Study Tpf-5(013).* McLean, VA Federal Highway Administration, 2006.
6. Huang, Y. H. *Pavement Analysis and Design (2nd Edition).* Upper Saddle River, NJ 07458 Pearson Prentice Hall, 2004.
7. Lu, P. and Tolliver, D. *Pavement Pre- and Post-Treatment Performance Models Using LTPP Data.* Journal of the Transportation Research Forum, Vol. 51, pp. 67-81, 2012.
8. Haider, S. W. and Dwaikat, M. B. *Estimating Optimum Timing for Preventive Maintenance Treatments to Mitigate Pavement Roughness.*Transportation Research Record: Journal of the Transportation Research Board, Vol. 2235, pp. 43-53, 2011.
9. Irfan, M., et al. *Evaluating the Cost Effectiveness of Flexible Rehabilitation Treatments Using Different Performance Criteria.* Journal of Transportation Engineering, Vol. 135, pp. 753-763, 2009.
10. Ozbay, K. and Laub, R. *Models for Pavement Deterioration Using LTPP.* Washington, D.C. New Jersey Department of Transportation, Division of Research and Technology and U.S. Department of Transportation Federal Highway Administration, 2001.
11. ARA, Inc., ERES Division. *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*. *Appendix GG-1: Calibration of Permanent Deformation models for Flexible Pavements.* Washington, D.C. National Cooperative Highway Research Program. Transportation Research Board, 2004.

12. Whites, T. D., et al. *Contributions of Pavement Structural Layers to Rutting of Hot Mix Asphalt Pavements.* Washington, D.C. Transportation Research Board. NCHRP REPORT 468, 2002.
13. Titus-Glover, L. and Darter, M.I. *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. Appendic PP: Smoothness Prediction For Rigid Pavements* Champaign, Illinois 61820 National Cooperative Highway Research Program (NCHRP), Transportation Research Board, National Research Council, 2001.
14. Lytton, R. L., et al. *Models for Predicting Reflection Cracking of Hot-Mix Asphalt Overlays.* Texas Transportation Institute, Texas A&M University, Texas Transportation Institute. Washington, D.C. NCHRP Report 669, Transportation Research Board, 2010.
15. Peshkin, D.G., Hoerner, T.E. and Zimmerman, K.A. *Optimal Timing of Pavement Preventive Maintenance Treatment Applications.* Washington, D.C. Transportation Research Board, National Research Council, NCHRP Report No 523, 2004.
16. Geoffroy, D.N. *Cost-Effective Preventive Pavement Maintenance.* Washington, D.C. Transportation Research Board, National Research Council, NCHRP Synthesis of Highway Practice 223, 1996.
17. Hicks, G.R., Fee, F. and Moulthrop, J.S. *Experiences With Thin and Ultra Thin HMA Pavements in the United States.* Sydney, Australia Australian Asphalt Pavement Association International Conference, 2000.
18. Johnson, A.M. *Best Practices Handbook on Asphalt Pavement Maintenance.* Minnesota Minnesota T2/LTAP Program, Center for Transportation Studies, 2000. University of Minnesota Report No. 2000-04.
19. Ohio DOT. *Pavement Preventive Maintenance Program Guidelines.* Ohio The Office of Pavement Engineering Report, 2001.
20. Wade, M., DeSombre, R.l and Peshkin, D.G. *High Volume/High Speed Asphalt Roadway Preventive Maintenance Surface Treatments.* s.l. South Dakota Department of Transportation. Report No. SD99-09, 2001.
21. Baladi, G. Y. *FHWA.* Washington, D.C. National Cooperative Highway Research Program, 2011.

22. Bolander, P.W. *Seal Coat Options: Taking Out the Mystery.* Kansas City, Missouri First National Conference on Pavement Preservation. Transportation Research Circular No. E-C078, 2005.
23. Gransberg, D. and James, D.M.B. *Chipseal Best Practices.* Washington, D.C. NCHRP Synthesis of Highway Practice 342, Transportation Reserach Board, National Research Council, 2005.
24. Rangaraju, P. R., Amirkhanian, S. and Guven, Z. *Life Cycle Cost Analysis for Pavement Type Selection.* Columbia, SC South Carolina Department of Transportation, 2008.
25. Lamptey, G., et al. Life Cycle Cost Analaysis for INDOT Pavement Design Procedures. West Lafayette, Indiana Indiana Department of Transportation, 2005.
26. Caltrans. *Life-Cycle Cost Analysis Procedures Manual.* s.l. State of California, Department of Transportation, Pavement Standards Team & Division of Design, 2010.
27. Walls III, J. and Smith, M. R. *Life-Cycle Cost Analysis in Pavement Design-Interim Technical Bulletin.* Washington, D.C. Federal Highway Administration, 1998.
28. Virginia DOT. *Life Cycle Cost Analysis Pavement Options.* Virginia Materials Division, Virginia Transportation Research Council, 2002.
29. Horne, W. B. and Dreher, R. C. *Phenomena of Pneumatic Tire Hydroplaning.* Washington, DC NASA Technical Note 2056, Langley Research Center, Langley Station, Hampton, Virginia, National Aeronautics and Space Administration, 1963.
30. Ong, G. P. and Fwa, T. F. *Modeling of the Hydroplaning Phenomenon.* s.l. Department of Civil Engineering, National University of Singapore.
31. Horne, W. B. and Leland, T. J. W. *Influence of Tire Tread Pattern and Runway Surface Condition on Braking Friction and Rolling resistance of a Modern Aircraft Tire.* Washington, DC NASA TN D-1376, Langley Research Center, Langley Station, Hampton, Virginia, National Aeronautics and Space Administration, 1962.
32. Pelloli, R. *Road Surface Characteristics and Hydroplaning.* Transportation Research Record, No. 624, TRB, National Research Council, Transportation Research Record, pp. 27-32, 1972.
33. Browne, A. L. *Dynamic Hydroplaning of Pneumatic Tires.*PhD thesis, North-Western University, USA, 1971.
34. Horne, W. B. and Joyner, U. T. *Pneumatic Tire Hydroplaning and Some Effects on Vehicle Performance.* Detroit, Michigan AE International Automotive Engineering Congress, 1965.

APPENDIX A

Literature Review and State-of-the-practice

Review of Pavement Treatments

Chipseal.

Description

A chipseal (can be called as a “seal coat”) is generally the application of single layer asphalt in the pavement followed by the rolling of aggregate (normally one stone thick) in to the asphalt (see Figure 2) *[1]*. Double chipseals are also common in practice; in that case, the second chipseal is put just over the first one as shown in Figure 5. In this process, the second overlying chipseal uses less asphalt and smaller aggregate compared to the first chipseal. A double chipseal provides better pavement quality and suitable for pavement with poor condition. Also, chipseal can be used at any time during the life span of a pavement *[2]*.

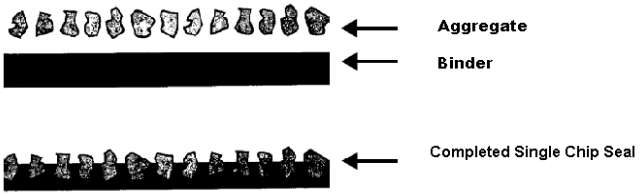


Figure 1
Single Chipseal *[3]*

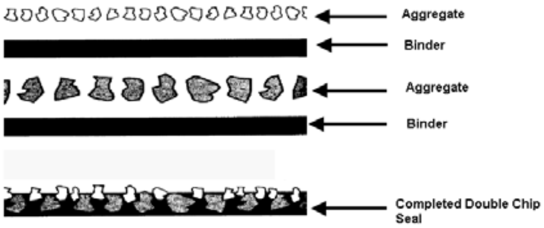


Figure 2
Double Chipseal *[3]*

The ideal benefits of a chipseal are easily comprehended in the context of preventive management program where the treatment is applied early in a pavement’s life *[1]*. Chipseals are appropriate to roads showing oxidization, raveling, bleeding, minor cracking, and reduced friction, but not to rutting *[2]*. Ohio DOT restricts chipsealing to low volume roads (< 2500 ADT) with rutting within half in. All cracks and patches are finalized within six months of chipsealing *[4]*. Although, Gransberg and James cite a study that determined crack sealing and patching should be done at least six months before chipsealing *[1]*.

There are variations in the application of standard chipseal which include the use of choke stones, fog seals, and slurry seals. Choke stone is a layer of smaller size aggregate applied to the chipseal without asphalt after the cover stone has been rolled. It is provided before opening to traffic. Choke stone fills the void in the pavement surface and prevents the larger aggregate from dislodging by acting as a lock in. It can also be called "sacrificial stone" or "scatter coat." A fog seal and slurry seal can also be provided to the chipseal to help filling the voids and restrict the loss of aggregate. The particular combination of a new chipseal and a slurry seal is called a cape seal and has the added benefit of reducing tire noise *[1]*. Other variations include polymer- modified asphalt binder which retains more chips from the chipseal, resulting in fewer cracked windshields *[5]* and is considered easy to work *[6]*. Chipseal can also be applied over paving fabric, which not only repairs the road surface, but performs as a waterproofing agent, protecting the subgrade and prevents reflective cracking *[6], [7]*. The advantages and disadvantages of chipseal are:

Advantage

- Technology is well known and widely used *[1]*
- Low cost for a sustainable pavement treatment *[8]*
- It performs well in all environmental zones *[9]*
- Effective at sealing medium-severity fatigue cracking *[9]*
- Protects pavement from ultraviolet rays from sun and moisture infiltration *[2]*

Disadvantage

- Loose chipseals in the pavement can damage vehicles *[8]*
- Increased road noise is associated with it *[1]*
- Failure of projects may happen without any specific cause *[1]*
- Successful treatment requires proper application rates of aggregate and binder *[10]*
- Reduced speed of vehicle is required after the treatment *[11]*
- Prone to snowplow damage *[12]*
- Road roughness not significantly improved *[13]*

Performance

Based on the literature review administered for this study, it seems the expected treatment life of a chipseal can vary significantly (Table 1 and 2). Based on a survey done by Gransberg and James, it seems that the performance of chipseal s in the USA is poorer than that of overseas; although it is not clear whether the data was qualitative or quantitative in nature *[1]*. Australia and the UK reported the use of chipseal in pavement on about 273000 and 213000 lane miles respectively, which is far more the reported 140000 lane miles used by the USA. Only a few states (California, Colorado, and Montana) use chipseal s if the ADT is greater than 20000, whereas it is commonly used in the UK.

A study by Gransberg and James displays that skid resistance and texture depth measurements are the primary criteria used to measure the performance of chipseal *[1]*. These criteria are especially convenient for the bleeding and raveling, the two most common distresses affecting the chipseals. Skid resistance and texture depth are measured quantitatively and according to ASTM E274 and ASTM E965, respectively. Measuring mean texture depth (MTD) by sand patch (ASTM E965) is the best indicator of performance of chipseal as determined by the Pennsylvania Transportation Institute *[10]*. Gransberg and James suggested that visual distress surveys are the most commonly used methods to determine the performance of chipseal and these periodic evaluations are done to determine when to use new chipseal but not to evaluate the performance of the chipseal *[1]*.

Table 1

Single chipseal treatment life as reported by various sources *[13]*

Reference	Treatment Life (years)	Notes
Bolander *[14]*	3 to 6	for ADT 100 to 500
Bolander *[14]*	4 to 12	for ADT < 100
Geoffroy *[15]*	4	median life in Oregon
Geoffroy *[15]*	4	average life in Indiana
Geoffroy *[15]*	4 to 7	according to FHWA
Geoffroy *[15]*	1 to 6	according to NCHRP
Gransberg & James *[1]*	5.76	US average based on a survey
Gransberg & James *[1]*	5.33	Canada average based on a survey
Gransberg & James *[1]*	10	Australia average based on a survey
Gransberg & James *[1]*	7	New Zealand average based on a survey
Gransberg & James *[1]*	12	South Africa average based on a survey
Gransberg & James *[1]*	10	United Kingdom average based on a survey

Hicks et al. *[16]*	3 to 5	average life in Ohio
Johnson *[2]*	3 to 6	expected service life

Table 2

Double chipseal treatment life as reported by various sources *[13]*

Reference	Treatment Life (years)	Notes
Bolander *[14]*	5 to 15	for ADT < 100
Bolander *[14]*	5 to 7	for ADT 100 to 500
Hicks et al. *[16]*	4 to 8	average life in Ohio
Johnson *[2]*	7 to 10	depending on type and amount of traffic
Maher et al. *[8]*	4 to 8	average life expectancy

A paper survey by Geoffroy was distributed to the United States, District of Columbia, Puerto Rico, Canada, and 37 local agencies to detail the average life extension of pavement provided by chipsealing among other things *[15]*. The reported minimum increase of life was two to four years and a maximum increase of life was seven to eight years. The most reported increase of life was five to six years. However, all the reported extension of life was based on perception rather proper mode of evaluation.

Analysis shows the average service life of chipseals in Kansas to be approximately four years with a maximum service life of nine years. It was found that applications of chipseals reduced transverse and fatigue cracking significantly and improved rutting condition *[13]*. Roughness was not significantly improved or actually increased *[13], [17]*. A life cycle cost analysis of chipseals in West Virginia and 46 other states indicate that average service life of a chipseal to be approximately six years *[18]*. The Nevada Department of Transportation has determined the service life of a chipseal to be five or more years *[6]*.

Chipsealing over paving fabric can extend the life of a chipseal by an additional 50% to 75% in warm climate areas. The pavement to be treated must have structural integrity, all small repairs completed, be clean and dry, and have the temperatures necessary to allow curing of the chipseal emulsion. Research has shown that some projects in the U.S. have been maintenance free with little to no reflective cracking after receiving this treatment for over 20 years *[7]*. One contractor's experience with this method has shown not only an increase in pavement life and a reduction in cost but also the prevention of oxidation and stripping due to the waterproofing quality of this method. A 90% reduction in reflective cracking was also observed and alligator cracked pavement was repaired without removal or replacement of damaged pavement *[19]*. Nevada also uses double chipseal over paving fabric as a waterproof layer and to delay the reflective cracks *[6]*.

Chipseal Cost

Tables 3 and 4 describe the year at which the projects were constructed (or made bid) in order to apprehend the time value of money. In 1999, the county of San Diego conducted a life cycle cost analysis which shows chipsealing over paving fabric to be more cost effective over a 30 year life cycle as shown in Table 5 *[7]*. The Washington State Department of Transportation has determined chipseal to be an initially cost effective alternative to overlay. However, it also determined chipseal to have increased user costs over time and roughness *[17]*. Another study calculated a lane/mile cost of $5,984 with a life of 4 to 6 years, based upon 24 chipseal projects in the New England area and a survey applied to 47 states *[18]*. Nevada's Department of Transportation cost of chipseal treatment is also listed in Table 6.

Table 3
Single chipseal costs per lane mile *[13]*

Cost/Lane Mile (12-ft width), $	**Location**	**Year Data Taken**	**Reference**
8,400 – 10,600	None specified	1999	Bolander *[14]*
5,500 – 7,500	OH	1997	Hicks et al. *[20]*
3,900	None specified	1999	Johnson *[2]*
5,600 – 8,800	None specified	2004	Maher et al. *[8]*
7,000 – 12,300	OH	1999	Ohio DOT *[4]*
8,000	SD	2000	Wade et al. *[10]*

Table 4
Double chipseal costs per lane mile *[13]*

Cost/Lane Mile (12-ft width), $	**Location**	**Year Data Taken**	**Reference**
13,000 – 17,600	None specified	1999	Bolander *[14]*
8,500 – 12,000	OH	1997	Hicks et al. *[20]*
10,600	None specified	1999	Johnson *[2]*
8,800 – 17,600	None specified	2004	Maher et al. *[8]*

Table 5

Cost comparison of various chipseal *[7]*

Surface Treatment	30 – year Cost ($)	Annual cost ($)
Single Chipseal with Crack Seal	5,205,000	174,000
Chipseal with Ground Rubber Paving Asphalt Binder	3,993,867	133,139
Single Chipseal Over Paving Fabric	2,615,000	87,000

Table 6

The Nevada Department of Transportation has determined the following costs *[5]*

Type of Treatment	Cost/Square Yard	Cost/Centerline Mile (26 ft. wide)
Chipseal (Single)	$1.20	$18,000
Chipseal (Double)	$2.40	$36,000
Chipseal (Double) Over Geotextile Fabric	$4.65	$70,000

Other Studies

To evaluate the use of lightweight and standard aggregate as well as fog sealing, three chipseal test sections of 250 m length were constructed in Colorado on State Highway 94 in August 1997 by Outcult *[21].* A control section of 250 m with no treatment was compared with the treated pavements. All cracks in the shoulders were sealed within the driving and passing lanes prior to the application of chipsealing. The transverse and longitudinal cracks between one – third and one – fourth in. were measured; the majority of cracks were transverse. Section I was provided with lightweight chips made of expanded shale having a unit weight 60% of the standard chips. Sections II and III were provided with standard weight chips. HFRS-2P emulsion was applied at 0.35 gal/sq yd on all three sections. Chips were applied at the rate of 12 lb/sq yd on Section I and at the rate of 25 lb/sq yd on both Sections II and III. Section III included a fog seal of HFRS-2P emulsion diluted 1:1 and applied at 0.05 gal/sq yd.

Outcalt concluded that chipseal s do “extend the life of the pavement by postponing environmentally induced cracking” and that lightweight chips offer the advantages of lower transportation costs and reduction of windshield damage compared to the standard chips. This study did not show any measurable benefit of a fog seal application on a newly constructed chipseal. There was very little chip loss in the three sections. There was no sign of bleeding and rutting. In general, after four years of construction, the chipseal sections were in better condition than the untreated control section *[21]*.

Iowa State University administered a study on thin maintenance surfaces for the Iowa Department of Transportation. Single and double chipseal performance was evaluated *[22]*. A summary of the construction of the chipseal test section studied in this program is provided in the Table 7. Data for surface condition index (SCI), skid resistance, and roughness index were measured before and after construction. On US 30, after two and half year of construction, only one of the chipseal sections performed better than the control sections. The section that received fog seal happened to show better performance. The chipseal and chipseal with slurry seal performed poorer than control section #2, and the standard chipseal hardly outperformed control section #1. The double chipseal experienced severe bleeding within a year of construction and had to be covered with a slurry seal. The late season construction was blamed for the poor performance of many of the surface treatments on US 30. In sharp contrast, all the chipseals on US 69 performed better than the control section on US 30. The single chipseal with HFRS-2P binder was performing the best two years after construction. Chipseals performed better than the other treatments when used on pavements having greater occurrence of cracking.

Shuler and Lord made a survey in which they found windshield damage can result when traffic is allowed on a fresh chipseal before the binder has cured sufficiently to resist dislodgement of chips. When 10% or less chip loss occurs during a sweep test, the chipseal is considered ready for traffic *[5]*. The objective was to develop a method to determine when emulsified asphalt chipseals have sufficient adhesive strength to resist the loss of chip.

Table 7
Iowa State University test section descriptions *[19]*

Test Section	Year Constructed	Highway	Aggregate Size(s)	Binder(s)	Treatments
Control 1	1997	US30	--	--	---
Control 2	1997	US30	--	--	---
Single	1997	US30	½-in.	CRS-2P	none
Single	1997	US30	½-in.	CRS	Slurry seal
Single	1997	US30	½-in.	CRS	Fog seal

Double	1997	US30	½-in. bottom, ⅜-in. top	CRS-2P	none
Control	1998	US69	--	--	---
Single	1998	US69	¼-in.	CRS-2P	none
Single	1998	US69	¼-in.	HRFS-2P	none
Double	1998	US69	½-in. bottom, ¼-in. top	HRFS-2P bottom,	none
Double	1998	US69	½-in. bottom, ¼-in. top	HRFS-2P top HRFS-2P bottom, CRS-2P top	none

A full-factorial experiment was designed for each emulsion according to the following model:

$$Y_{ijkl} \text{ equals } +A_i+W_k+M_l+AW_{ik}+AMil+WMkl+AWMikl+{}_{ikl} \qquad (1)$$

Where, Y_{ijklm} equals chip loss, A_i equals effect of aggregate i on mean, W_k equals effect of water removed k on mean, M_l equals effect of aggregate moisture l on mean, AW_{ik}, etc. equals effect of interactions on mean, e_{iklm} equals random error for the i^{th} aggregate, j^{th} emulsion, k^{th} water removed, and l^{th} replicate.

Chipsealing over paving fabric has been found successful on roadways that are structurally sound. Small, isolated areas of distress require repair for this treatment to have the same effectiveness. Cracks wider than ¼ in. (0.098 cm) should be filled or sealed prior to treatment; otherwise there may be chip loss over the underlying crack *[7].* It has been found that the treatment life is significantly improved due to application of fabric (Table 8).

A liquid asphalt tack coat is applied to the paving fabrics until saturation, acting as a moisture barrier. When the paving fabric is properly saturated and applied, the chipseal can then be applied at the same rate recommended for on an asphalt concrete pavement. The method of placement of the fabric and the chipseal is not determined by the road's average daily traffic (ADT) but by the traveling speed of the road (high-speed vs. low-speed).

Chipsealing over paving fabric was proven to be an effective pavement preservation treatment for fatigue cracking, waterproofing, and prevent reflective cracking.

Table 8

Experience of state agencies with chipseal over paving fabric

Agency	Treatment Life (years)	Notes
Northern California	25	double chipseal
Southern California	22	applied in 1987
District of	5	applied in 2005
Columbia	8	DOT estimated
Oklahoma	20	maximum
South Carolina	11	
Virginia		Evaluated in 2005

This surface treatment is best suited for roads that have, sound structural section, straight or gradually curved, few intersections or driveways, vertical grades equal to or less than 10%, and pavement cross-slope that prevents ponding on the roadway. On the other hand, fabric placement is not recommended at the following locations:

- Vertical grades greater than 10%
- Horizontal curves equal to or less than 200 ft radius
- Cul-de-sac bubble portions
- 100 ft. approaching controlled stop intersections (traffic signals or STOP/YIELD traffic signs)
- Climate conditions where freeze-thaw cycles are severe
- Wet low lying areas without proper drainage
- If the roadway experiences surface water ponding such as in a dip section, or anytime after product placement, or if the subgrade allows any water penetration

An analysis of service life of various pavement preservation techniques, primarily in comparison to chipseal demonstrates the more consistent performance of chipseal, longer service life, both average and maximum, and effective treatment for transverse cracking, fatigue cracking and rutting. The analysis also shows chipseal has only a limited effect on roughness.

Using the Highway Development and Management System (HDM-4), pavement performance and cost effectiveness were assessed using many characteristics by Pierce et al. *[17]*. Although chipseal was determined to be the most cost effective preservation treatment, it was concluded that a future overlay would be needed in order to decrease user costs and decrease roughness *[17]*.

A survey was conducted of 47 states to determine the average and expected service life of various types of pavement preservation treatments *[18].* The results of the survey were used to develop a model to determine the appropriate time and method of rehabilitation of a pavement for optimal preservation strategy. Sensitivity analysis was also included to determine the effects of the various parameters included in the model. Several equations to determine PSI gain and optimal effectiveness were used for the model

$$\Delta PSI \text{ equals } 0.3325 * (PSI - 1.433) \qquad (2)$$

Where, ΔPSI equals gain in pavement serviceability owing to chipseal activity, and PSI equals PSI at time of chipseal application.

$$\log(SC) \text{ equals } 3.6101 + (-\ 0.1034 * PSI) \qquad (3)$$

Where, SC equals cost of performing chipseal ($ per lane-mile), and PSI equals pavement serviceability index at time of chipseal .

$$PSI \text{ equals } 2.86+C1+C2+C3+C4-1.02*\exp(-4*ESALS)-0.015(AGGR)+0.075(TMAX)- 2.98*\exp(-3*FT)-0.125(SN)-0.33(YEAR)+0.005(YEAR)^2 \qquad (4)$$

Where, ESALS equals cumulative value of 80-kN equivalent single axle loads, AGGR equals aggregate spread rate for chipseal project (lbs/yd2), TMAX equals maximum average yearly temperature that pavement may experience, FT equals total number of freeze-thaw cycles that pavement may experience over course of one year, SN equals structural number prior to application of chipseal, YEAR equals service year of the project (year of construction is year 0), C1 equals constant for specific binder type, C2 equals constant for binder type used in first structural layer below chipseal, C3 equals constant for maximum nominal aggregate size, and C4 equals constant for combination of binder type used in chipseal and binder type used in first structural layer below chipseal .

It is concluded that pavement condition at the time of preservation treatment has a significant effect on the long-term effectiveness of the applied preservation treatment. Although a preventative maintenance treatment maintains the structural capacity of a pavement, therefore extending the life of the pavement, it does not add structural capacity to the pavement.

Low-volume roads receive the least funding so cost-effective methods of pavement rehabilitation need to be utilized in pavement preservation *[6]*. Sections were tested for roughness, subjected to the falling weight deflectometer test and the condition surveyed. Samples were laboratory tested for resilient modulus, strength and susceptibility to rutting. The recommendation for type of treatment is based on the functional or structural deficiencies. Pavement preservation does not improve the structural characteristics of a pavement. In order to be suitable for treatment, the pavement must have deteriorated to the point where simply applying an overlay would only result in the appearance of reflective cracks in a relatively short time and the rehabilitation alternatives must eliminate or delay reflective cracking for a period of time such that the cost is economically feasible *[6]*.

Summary of Chipseal

Chipseal is a widely used pavement maintenance treatment in which asphalt binder and aggregate are sequentially applied to an existing pavement and rolled in place. The treatment supposedly attends to cracking, bleeding, raveling, oxidation, and reduced friction. The expected treatment life for a single application can be about five years and for a double application can be about seven years. It is relatively low cost despite its durability. There are scopes of using variations like choke stone, fog seals, and slurry seals, although results are not conclusive regarding the use of these materials with the standard chipseal. The condition of the pavement at time of treatment has a large impact on the long term effectiveness of the treatment. Laboratory results show a significant difference between polymer and non-polymer modified emulsions, the modified emulsions retaining more aggregate than the non-modified emulsions, with one exception, RS-2P, which gave the poorest results of the modified binders. A strong relationship also appears between emulsion cure time and chip loss. Chipsealing over paving fabric also significantly extends the life of the maintenance treatment. There are conditions where this treatment is not effective, such as cold weather regions and roadways which are very susceptible to pounding or water penetration through the subgrade.

Crack Sealing.

Description

Cracking in pavement happens as a result of stress built up in a layer that overcomes the tensile or shear strength of the pavement. Crack sealing is typically used to seal cracks that open and close on a seasonal basis, known as "working cracks." This method of pavement preservation is most effective when applied to pavement that is structurally sound with limited cracking *[23]*. Working cracks transversely oriented to the centerline of the pavement require the placement of specialized materials in order to reduce the intrusion of incompressible particles into the crack and prevent water from infiltrating the base layers of the pavement *[24]*. Crack types are fatigue cracks, longitudinal cracks, transverse cracks, block cracks, reflective cracks, edge cracks, and slippage cracks *[3]*. Crack Sealing should be performed in cooler weather when the cracks are wider to get better performance *[4]*. Due to the moving nature of working cracks, a suitable crack sealant must be able to *[3]:*

- Remain adhered to the walls of the crack
- Elongate to the maximum opening of the crack and recovering to the original dimensions without rupture
- Expand and contract over a range of service temperatures without rupture
- Resist abrasion and damage caused by traffic

The advantages and disadvantages of the treatment are as follows:

Advantage

It is relatively low cost compared to other preventive treatments and considered as an efficient way to protect the pavement from water infiltration *[25]*. The technology is widely used and well known. It is also effective in reducing severity of pavement tenting in cold regions *[26]*.

Disadvantage

Crack Sealing has relatively short lifespan and bleeding through overlay may result. The cost effectiveness is also questionable *[25]*.

Performance

According to FHWA, the performance life of a treatment is influenced by the amount of crack preparation and the type of material used *[27]*. Crack sealants can provide a life of up to nine years depending on the amount of preparation and material used. According to 11 projects in 4 states, application timing ranges from 1 to 38 years, with a service life of up to 4 years *[24]*.

Other studies indicate an extended pavement life of two to six years when a crack seal is applied when the pavement condition ranged from good to fair *[23]*. Research conducted in Minnesota determined that crack sealing can reduce the roughness of the road and the height of tented cracks *[26]*. A summary of crack sealing life is presented in Table 9.

Crack Seal Cost

Based on 11 projects in 4 states, the cost of crack sealing ranges from $883 to $9,792 *[24]*. Kreis et al. found that every preventative maintenance dollar spent before the pavement condition decline accelerates saves at least four reconstruction dollars. Table 10 indicates that the cost of crack seal can be anywhere between $1,000 to $11,750 *[28]*.

Table 9

Crack treatment life as reported by various sources

Reference	**Treatment Life (years)**
Crack seal in Indiana *[15]*	2.2
Route and seal in Ontario *[15]*	2 to 5
Crack fill in New York *[15]*	2
Route and seal in New York *[15]*	2 to 5
Average reported value in Minnesota, performed on new pavement *[15]*	7 to 10
FHWA *[27]*	9

Table 10

Crack seal costs per lane mile

Cost per lane mile, (12-ft width), $	**Sources**
1,000 – 4,000	Ohio DOT *[4]*
2,900 – 11,750	*[29]*
6,900 (typical)	*[29]*

Other Research Studies

Wu et al. used specific states for this study. In order to be selected, the states must meet certain criteria. They must have an established Pavement Management System or other system for gathering information about pavements and use several of the available treatments for pavement preservation and rehabilitation *[24]*. The objective was to find how effectively preventive maintenance treatments and rehabilitations extend the service life of pavements. A total of 15 projects from Kansas, Michigan, Minnesota, Texas, and Washington were analyzed. Treatments were initially applied anywhere from 2 to 13 years in the life of the pavement and there were wide ranges of AADT and truck percentages. Chipseal was mainly used for raveling and most types of cracking. States use different methods to measure pavement condition and determine treatment.

Yut et al. compared the service life of perpetual pavements. Two highways with similar structures and pavement age were selected for analysis *[23]*. The preservation treatments used were thin overlay and crack sealing. It was determined that crack sealing early in the life of the pavement resulted in a significant increase in the life of the pavement, delayed major rehabilitation and dramatically decreased costs. An analysis of Kentucky roads and the practices of pavement preservation in other states suggest a schedule of preservation treatments can greatly reduce costs as well as systematically improve the quality of roads in Kentucky *[28]*.

Pavement tenting occurs in localized sections of a roadway that undergo heaving at pavement cracks or joints during winter weather in cold regions. The research investigated whether crack sealing, deicing materials and sands affected pavement tenting. It was determined that crack sealing greatly reduced the severity of pavement tenting *[26]*.

Summary of Crack Seal

Of the many pavement preservation treatments, crack sealing is cheapest but effective in the short term. Many studies have contributed to the belief that it is an excellent preservation treatment that is most effective when used early in the pavement life. The pavement must be structurally sound and the cracking must not be severe. The timing of this treatment however is subjective and the conditions for its use and the materials used are not consistent.

Microsurfacing.

Description

Microsurfacing treatments are widely used for both pavement maintenance and preventative measure. Microsurfacing is a mixture of polymer modified asphalt emulsion, graded aggregates, mineral filler, water, and other additives. The mixture is prepared by a specialized machine and placed on a regular basis by combining the materials simultaneously (Figure 3). The process in which the microsurfacing machine spread the free flowing composite material on the underlying pavement is shown in the figure. The mixture should be evenly distributed to form an adhesive bond to the pavement *[30]*. The mixture contains asphalt emulsion that breaks onto the pavement surface through heterogeneous or homogenous flocculation. Particles of asphalt coalesce into films, creating a cohesive mixture. The mixture then cures, by loss of water, into a hardwearing, dense-graded asphalt/ aggregate mixture that is bonded to the existing pavement *[30]*. Microsurfacing cannot increase the structural ability of the pavement.

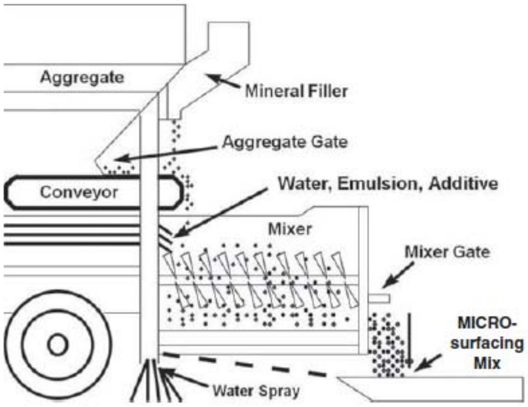


Figure 3
Schematic of a micro-surfacing machine *[30]*

Advantage

- With favorable weather, roads can be opened to traffic within one hour of treatment *[31]*
- Can be used on both high volume and low volume traffic *[12]*
- Less vulnerability to snowplow damage *[12]*
- No windshield damage due to loss of rocks *[32]*
- Better for turning and stopping traffic action *[32]*
- Ability to be placed at night or in cooler temperatures *[3]*
- Rut filling of pavements can be easily done *[3]*

Disadvantage

- Does not add any structural capacity to an existing pavement *[3]*
- Requires special equipment for treatment thus making it costly *[10]*
- Will not prevent cracks in the underlying pavement from reflecting through to the surface *[33]*
- Success of the treatment is largely based on experienced worker and proper mix *[34]*

- Rapid blade wear on snow plows *[22]*
- Does not add any structural capacity to an existing pavement *[3]*
- Ingredients must be properly selected to work together *[2]*

Performance

The summary of the treatment life from various sources is shown in Table 11. The data in table indicates that treatment life is between 2 to 15 years with an average of about 6.5 years. In Arkansas, Kansas, and Pennsylvania, rutting returned in 3 to 5 years. In Pennsylvania, friction loss of 50% occurred in 5 years. It is important to note that the treatment life is based upon observation and professional assessment, not quantitative analysis of the condition. California reports a treatment life of 7 to 10 years *[3]*. Smooth joints, edges and shoulders can be difficult to achieve due to the quick breaking of the micro-surfacing slurry. This takes skill to perform correctly and possibly by hand-working the slurry *[3]*.

The increase of pavement life from microsurfacing is difficult to measure conclusively, although, some insight is presented here from the examined literature. Indiana provides an extension of approximately three years *[35]*. The same pavement age and life extension was reported for both full-depth AC and AC over PCC pavements. According to Peshkin and Hoerner, the Michigan Department of Transportation recommends a life extension of three to five years for single course microsurfacing and four to six years for multiple course microsurfacing application *[36]*.

Microsurfacing Cost

The average cost based on data obtained from many states is \$12,600 per (12 ft. wide) lane mile. The cost varies based on regional availability and costs of materials and contractors (Table 13). In Alaska, the costs are based on location, either Juneau or Anchorage, and measured in square yard- in. layer. These costs are \$6.80 per yd^2-in in Anchorage to \$13.50 per yd^2- in Juneau *[37]*. A project sponsored by the FHWA reports cost/lane mile ranges from \$19,436 to \$32,698, based on 3 projects each in Minnesota, Michigan, and Texas *[24]*. According to LTRC, the average unit cost of micro micro-surfacing equals \$3.20/sq.yd where, unit cost equals construction cost plus maintenance costs and EAC equals (\$3.20/sq.yd.)/(7years) with \$0.46/sq.yd./year for expected life where, EAC equals unit cost of treatment/expected life of treatment.

Table 11

Micro-surfacing treatment life as reported by various sources

Sources	Treatment Life (years)
Geoffroy *[15]*	4 to 7
Johnson *[2]*	7
Labi et al. *[38]*	5 to 15
Peshkin et al. *[9]*	4 to 7
Smith and Beatty *[32]*	7 to 10
Wade et al. *[10]*	4 to 7
Bausano et al. *[39]*	6 to 7
Lyon and Persaud *[40]*	5 to 7
Watson and Gared *[41]*	5 to 7
Temple et al. *[42]*	4 to 10
Chehovits and Galehouse *[43]*	2 to 5

Table 12 provides a quick comparison between microsurfacing and slurry seal pavement treatments.

Table 12

Differences between Microsurfacing and slurry seal *[3]*

Differences	Micro-Surfacing	Slurry Seal
Asphalt Emulsion	Always polymer modified, quick set	could be polymer modified
Aggregate Quality Gradation	Stricter spec. for sand equivalent; use only Type II and Type III	Can use Type I, II and III
Additive Break	Chemical break largely independent of weather conditions	Breaking and curing dependent on weather conditions
Mix Stiffness Equipment	Stiffer mix, use augers in the spreader box and secondary strike-off	softer mix, use drag box
Applications	Same as slurry seal + rut filling, night work, correction of minor surface irregularities.	correct raveling, seal oxidized pavements, restore skid resistance

Other Research Studies

A survey was sent to all 50 states as well as Washington D.C. and multiple Canadian provinces by Cuelho et al. *[25]*. Of the 62 surveys sent out, 47 replies were received, including five from Canadian provinces. The highest costs treatments also tend to have the highest average treatment life. Once it is determined that a preventive treatment is necessary, the treatment selected is most often the treatment with which the department has had the most experience. The most frequently used treatments, in order, are crack sealing, thin overlay, chipseal, drainage features and micro-surfacing. Wu et al. selected specific states for this study. The states must meet certain criteria such as: (i) have an established Pavement Management System or other system for gathering information about pavements and (ii) use several of the available treatments for pavement preservation and rehabilitation *[24]*. The objective was to find how effectively preventive maintenance treatments and rehabilitations extend the service life of pavements. A total of 15 projects from Kansas, Michigan, Minnesota, Texas, and Washington were analyzed. Treatments were initially applied anywhere from 1 to 15 years in the life of the pavement and there were wide ranges of AADT and truck percentages. Micro-surfacing was mainly used to provide a skid-resistant surface and to repair rutting. States use different methods to measure pavement condition and determine treatment.

Table 13

Micro-surfacing costs per lane mile *[25]*

Cost/Lane Mile (12-ft width), $	Location	Sources
6,700 – 13,100	None specified	Bolander *[14]*
1,000 – 1,500	AR	Geoffroy *[15]*
5,000 – 7,000	TN, SUT(1)	Geoffroy *[15]*
7,000 – 10,000	MI, MS, MO, NC,OH	Geoffroy *[15]*
10,000 – 15,000	ID, TX, WI, IN	Geoffroy *[15]*
15,000 – 25,000	KS, VA, ON(2)	Geoffroy *[15]*
9,100	IA	Jahren & Bergeson *[22]*
10,400	IA	Jahren & Bergeson *[22]*
10,600 – 14,100	None specified	Johnson *[2]*
21,600	IN	Labi et al. *[38]*
26,800	IN	Labi et al. *[38]*
12,000 – 34,100	LA	Temple et al. *[42]*
20,600	LA (average)	Temple et al. *[42]*
8,800	None specified	Wade et al. *[10]*
8,800 – 14,100	OH	Wade et al. *[10]*
6,000 – 14,200	OK	Wade et al. *[10]*

Notes: (1)Salt Lake County, Utah; (2)Ontario, Canada

Labi et al. developed a methodology to determine the long term benefits of microsurfacing in

Indiana, where about 173 lane miles received the treatment. Pavement condition and distress, climatic conditions, and relative traffic volumes were the parameters they used as parameters to evaluate the data *[38]*. Severe climate conditions were defined as an annual freeze index beyond 60 degree-days. High traffic loads were defined as having an annual loading exceeding 1 million ESALs (equivalent single axle loads). The service life, increase in average pavement condition, and the area bounded by the treatment performance curve were taken as three measure of effectiveness (MOEs).The pavement condition rating (PCR), rutting, and surface roughness were considered as indicators for each MOE. The matrix of MOE and indicators provide inconclusive results. High traffic volume has less effect than the severe climatic conditions in case of rutting of microsurfaced pavements. The relative effect of climate and high traffic volume on treatment life based on PCR and surface roughness was not measurable.

Summary of Microsurfacing

There is less disruption of road use, better wear in turning and stopping areas and less aggregate loss. The improvement in rutting may not last long enough to justify the high cost of the treatment. Agencies using micro-surfacing can expect a 4 to 7 year life span of the treatment and a pavement life extension of 4 years or more. Micro-surfacing does not address any structural issues the pavement may be experiencing and is not suitable for areas that have not been repaired prior to the application of the micro-surfacing layer or areas that need structural remediation.

Thin Overlay.

Description

Thin overlay is a preventive maintenance treatment where HMA is applied to milled or unmilled existing pavement. The overlay is between 0.75 and 1.50 in.es thick and the HMA typically consists of plant-mix asphalt cement and aggregate. The three general categories of thin overlay mixes are determined by their aggregate gradation and they are dense-graded, open-graded and gap-graded aggregate mixes *[25]*. Dense graded mixtures have an aggregate composition that is continuously graded (sized) from the largest to the smallest aggregate in the system. They are mixed in a continuous drum type hot mix plant or a batch plant. Open Graded mixture is a surface course with an aggregate gradation that gives an open void structure as compared with conventional dense graded asphalt concrete *[20]*. Air void content typically ranges between 15 to 25% in OGFC mixtures in a highly permeable mixture relative to HMA. A gap graded mixture consists of an aggregate grading that has a missing fraction, generally medium-sized particles. Gap-graded aggregate is used in stone matrix asphalt (SMA) mixes with a stabilizer. SMA was developed to resist wear by tires and normally considered more durable than other mixes *[44]*. An appropriate asphalt grade should be selected based on the climatic region and anticipated distress mode. Asphalts could be modified to adjust properties for these conditions. It is recommended to mill the surface when segregation, raveling, or block cracking are present *[45]*. The advantages and disadvantages of thin overlay are as follows:

Advantage

- Reduce roughness and improve ride quality *[9]*
- Works well in all climate conditions *[25]*
- Noise controlling capacity *[9]*
- Provides minor amount of structural enhancement *[25]*
- Increase surface friction of the pavement *[9]*
- Extend the life of the pavement *[9]*
- Reduce the moisture infiltration of pavement *[9]*

Disadvantages

- Can be susceptible to delaminating, reflective cracking, and maintenance problems *[2]*
- Unsuitable for use on PCC pavements with poor load transfer characteristics *[46]*
- Curb and bridge clearance may be an issue without milling *[2]*

Performance

Thin overlay treatment life averages 8 years, with an average estimate of pavement life extension of 10 years (Table 14). However, the pavement life extension is based on qualitative perceptions rather than qualitative analysis *[25]*. A study of Ohio roads found that thin overlay had a service life of 4- 9 years when applied to composite pavements and 6-12 years for flexible pavements *[47]*.

According to Hicks et al., both the dense graded and open graded thin overlays have approximately 2 to 10 years of life, but commonly remains between 4 and 6 years *[20]*. The life of the treatment is directly affected by the condition of the existing pavement that received the overlay, environmental conditions in which the overlay was placed, and the traffic loading *[3]*.

Thin Overlay Cost

The cost of thin overlay varies with the thickness of the overlay, but Cuelho et al. estimates the cost at $14,600 per lane mile *[25]*. A study of roads in Kentucky found that every preventative maintenance dollar spent before the pavement condition decline accelerates saves at least four reconstruction dollars. For thin overlay, the per lane mile cost can also vary based on the road type, primary, secondary, state, rural, interstate, etc. *[28]*. In Ohio, it was estimated that thin overlay costs were $58,856 per lane mile on composite pavement and $53,995 per lane mile on flexible pavements found that thin overlay is cost effective for all pavements in all conditions and the cost of thin overlay varies from $3.92 to $5.61 per square yard *[47], [48]*. Table 15 provides the cost for thin overlay from other sources.

Table 14

Thin HMA overlay treatment life as reported by various sources

Sources	**Treatment Life (years)**
NCHRP *[15]*	> 6
New York State DOT *[15]*	8
FHWA *[15]*	8 to 11
Ohio *[16]*	7 to 10
Min, average, max (respectively) *[16]*	2, 7, 12
Minnesota *[2]*	5 to 8
Ohio *[4]*	8 to 12
Peshkin et al., *[9]*	7 to 10
OGFC in Florida *[10]*	10 to 12

Table 15

Thin HMA overlay costs per lane mile

Cost per Lane Mile 12-ft width, ($)	**Year Data Taken**	**Sources**
12,300	2000	Hicks et al. *[16]*
15,000 – 17,000	1997	OH (1 to 1.5 in. thick) *[16]*
17,600 – 25,000	1999	OH *[4]*
12,300 – 14,100	2001	Dense-graded *[9]*
11,900	2000	Dense-graded, 1 in. thick *[10]*
8,800 – 10,000	2000	open-graded, 1 in.thick *[10]*
14,200 – 16,600	2000	SMA, 1 in. thick *[10]*

Other Research Studies

A survey was sent to all 50 states as well as Washington D.C. and multiple Canadian provinces by Cuelho et al. *[25]*. Of the 62 surveys sent out, 47 replies were received, including 5 from Canadian provinces. The costly treatments also tend to have the highest average treatment life. Once it is determined that a preventive treatment is necessary, the treatment selected is most often the treatment with which the department has had the most experience. The most frequently used treatments, in order, are crack sealing, thin overlay, chipseal, drainage features, and micro-surfacing.

An analysis of Kentucky roads and practices of pavement preservation in other states suggests a schedule of preservation treatments can greatly reduce costs as well as systematically improve the quality of roads in Kentucky *[28]*.

An analysis of the performance of thin overlay on Ohio roads was undertaken by Chou et al., in order to determine the cost effectiveness of the treatment, to develop a selection process for pavement sections suitable for the treatment and to determine a schedule for application of the treatment to maximize the benefit and decrease maintenance costs *[47]*.

Pavement preservation treatment service life and cost-effectiveness were estimated and evaluated by using performance models and condition ratings for application of preservation treatments and overlays. The most cost-effective approach is to apply a preservation treatment early in the pavement life. However, treatment performance and cost-effectiveness may vary according to local conditions, costs and quality of construction *[48]*. Zhou and Scullion, conducted a study by focusing on a new mix design procedure, construction and performance of one overlay project in Fort Worth, Texas *[46]*.

Summary of Thin Overlay

Thin overlay is one of the most widely used pavement preservation treatments. It is seen as cost effective by many departments and can be applied to many types of pavements, road systems, to pavements in a variety of conditions and in any climate. An advantage of the use of thin overlay over other popular treatments is that it also provides a slight structural enhancement.

Whitetopping.

Description

Whitetopping is a thin overlay of Portland cement concrete (PCC) over the prepared surface of an existing asphaltic concrete pavement. The PCC surface is partial-depth sawn into panels. The width of these panels is calculated based on the thickness of the PCC overlay *[49]*. Bonding with the HMA and thickness are the main indicators of modern whitetopping. Three different categories are found in the practice *[50]*. Conventional whitetopping is a concrete overlay of 200 mm (8 in.) or more, designed and constructed without consideration of a bond between the concrete and underlying HMA. Thin whitetopping (TWT) is an overlay which is greater than 100 mm (4 in.) and less than 200 mm (8 in.) in thickness. In most of the cases, this overlay is designed and constructed with an intentional bond to the underlying HMA. And finally, Ultrathin whitetopping (UTW) is an overlay with a thickness equal to or less than 100 mm (4 in.); this overlay needs a bond to the underlying HMA to perform well. Based on the literature review, whitetopping has gained popularity as a preventive treatment. The condition of the existing asphalt pavement is important. A good bond between the PCC overlay and the existing HMA is recommended *[50]*. In Figure 4, the difference between the stress behavior of bonded and unbonded whitetopping is shown.

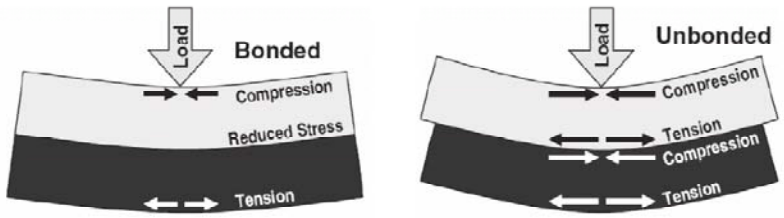


Figure 4
Behavior of bonded and unbonded whitetopping *[43]*

Advantages

- Suitable for severe rutting and related pavement distresses *[49]*
- Suitable for treating pavements experiencing raveling *[51]*
- Increase the reflection of lights and thus improving safety *[50]*
- Reduced operational cost due to lower demand of external lighting *[50]*
- Environmental benefit due to cooling effect owing to lower absorption of solar energy *[50]*
- Resistance to fuel spillage *[52]*

Disadvantage

- Not suitable for pavements in poor condition or those with deteriorated longitudinal seams or asphalts that are susceptible to stripping *[51]*
- Joints near wheel paths experience corner cracking *[49]*
- Axle loads greater than the standard 18 kips accelerate deterioration *[51]*
- Rutting in the HMA layer can be aggravated with the presence of high strain and moisture *[53]*

Performance

The weather and existing pavement conditions play a large role in the success of this type of pavement preservation. Milling and the use of stringlines for grade control are crucial for increasing bonding and to reduce waste from concrete overruns *[49].* A Minnesota study found that the performance of whitetopping is closely related to the traffic loading, layer bonding, and placement of wheel loads. On test sections placed on a heavily traveled interstate, reconstruction was required after 5 years *[54].* The major distresses affecting whitetopping are corner and mid-slab cracking, joint faulting and joint spalling *[51].* An Iowa study found a performance life of over ten years *[55].*

Whitetopping Cost

A study of the construction and performance of whitetopping in Illinois yielded a cost range of $12.73 to $40.19 per square yard, with some of the variance depending on the thickness of the overlay and the amount of saw-cutting required *[49].* Analysis of three whitetopping projects in Wisconsin yielded a cost range of $36.58 to $51.40 per square yard *[51].*

Other Research Studies

A study of the construction and early performance of several sections of whitetopping in communities in Illinois was done by Winkleman *[49].* Variations in conditions of the existing roads, local conditions and various construction practices and the effects on performance were analyzed.

Burnham made a forensic study of the performance of test sections placed on a Minnesota interstate instead of the typical application on lower volume roads in order to accelerate results *[54]*. The deterioration on the panels was documented and the causes determined. It was concluded that the main causes for failure were debonding, joints placed close to wheel paths and reflective cracking. The inclusion of polyolefin fibers decreased the severity of the cracking but not enough to defray the extra cost.

Wen et al. conducted a research consisting of analyzing the whitetopping and ultra-thin whitetopping projects in Wisconsin *[51]*. The effects of design and construction elements were found by conducting a forensic investigation. The performance of these projects was assessed and a service life was estimated for these projects, including a design and life cycle cost analysis. Cable et al. conducted a study of Iowa Department of Transportation whitetopping projects identified all performance indicators over the 10-year evaluation period for many variable combinations *[55]*. The report summarizes the research methods and results, and identifies future research ideas to aid in the successful implementation of whitetopping as a pavement rehabilitation option.

Summary of Whitetopping

Whitetopping is a very cost effective pavement preservation treatment. It can be used in a wide variety of climates and pavement conditions. When applied in ideal conditions, it can last ten or more years, significantly longer than many other treatments.

Full Depth Concrete Repair.

Description

Full depth concrete repair is a restoration technique for pavement. It strengthens slab structural integrity and improves ride quality. It prevents the pavements from further deteriorating and increase the life of pavement. Full depth repair includes a full depth slab removal, repair of the disturbed base, and then a cast in situ replacement of an existing rigid pavement. Minimum length requirement of a replaced lane is 6 ft. It is an effective, permanent treatment to repair pavement distresses with nearby joints and cracks. It is required to prepare an existing damaged pavement for preventive measures *[56]*. Selection of wide range of material is available for full depth repair depending upon the project's environmental, design, and funding requirements *[57]*. Some advantages and disadvantages of the full depth concrete repair are as follows:

Advantage

- Restore slab structural integrity

- Address distresses like longitudinal cracks, transverse cracks, blowup, joint spalling, and punchouts
- Cost effective when the distressed are is larger

Disadvantage

- Not suitable for smaller areas
- Extensive work required.
- Not a long term solution for material related distress

Performance

With proper design and construction, a good long term performance of up to 10 years can be achieved by full depth repair, although the performance of full depth repair varies due to inadequate design, poor load transfer mechanism, and poor construction quality. Effectiveness of full depth repair may be hampered due to the prior condition of distressed pavement. A study in Pennsylvania on the performance of various pavement restoration activities revealed that the life of full-depth repairs was about 5 years, although the researchers acknowledged that many of these repairs were placed on pavements that had deteriorated beyond the recovery point, where full depth repair can perform well *[58]*. In some cases, the thickness of full depth repairs can be increased to 2 to 4 in. thicker than the existing slab to increase the performance of treatment. They are:

- Anticipation of heavy traffic along with early opening
- Previous records of full depth shows a history of cracking
- Disturbed base/sub-base material is replaced with PCC during the treatment *[59]*

Cost

The cost for full-depth repairs on JCP varies significantly based on some factors, mainly locality, site conditions and traffic. Cost in 2000 for 1.8 m (6 ft) repairs on a 250-mm (10 in) slab range from \$60/m^2 to \$120/m^2 (\$50/yd^2 to \$100/yd^2), with many falling between \$78/m^2 and \$84/m^2 (\$65/yd^2 and \$80/yd2). Repair costs for CRCP are significantly higher. As the highest cost items for full-depth repairs are full-depth sawing and joints (including load transfer), the unit costs of repair can be reduced significantly when a larger area is involved. Costs in 2000 for 9-m (30-ft) slab replacements range from \$54/m2 to \$78/m^2

(\$45/yd^2 and \$80/yd^2).

The replacement of the entire slab is a more cost-effective solution than the placement of a series of smaller repairs within the slab, and is more reliable as it increases the pavement performance *[56]*.

Patching.

Description

Patching is a process where the material in a highly distressed area is either removed or additional material is added to treat the distressed area of the pavement. Patching is often done in order to prepare the pavement for other form of corrective measurements. It helps to improve the condition of the pavement so that other treatments can be used without any hindrance. Maximum performance is achieved by patching when the boundaries of the distressed area are distinguished properly and cut; also, the failed material is removed and the underlying material compacted. After patching, the distressed area is treated or strengthened to carry a significant amount of traffic *[3]*.

The primary methods used to perform patching are temporary, semi-permanent, or permanent treatments. The method should be selected based on the traffic level, repair time, and the availability of the resources. Although, patching is best done in moderate weather, it can be applied in cold weather. The primary materials used for pothole patching are Hot-mix Asphalt (HMA), Cold-mix Asphalt, Aggregate/Asphalt Emulsion Combinations, and Special Patching Mixtures *[3]*.

Advantages

- Repair localized distress and reduce the pavement roughness
- Improve motorist safety.
- Reduce the rate of pavement deterioration.
- Repair a pavement prior to overlay for improved support.

Disadvantages

- Patching localized distresses can disguise severe structural distress in the pavement.
- Cost of the repair may exceed the resulting benefits of reduced overlay thickness or extended service life of the overlay.

Patching Cost

The cost of hot-mix asphalt varies greatly throughout the United States. Typical costs of HMA material is between $27.50 per metric ton and $44 per metric ton. However, costs of the actual patching operation will have to consider the equipment needed, the manpower required, and the productivity of the operation. The quality of cold mixtures can vary considerably. The cost for these materials ranges from approximately $33 per metric ton to $88 per metric ton. These prices reflect only the cost of the material, and do not include other costs, such as shipping, labor, or placement. Estimates of costs to place material have been estimated at anywhere from $126 per metric ton to $374 per metric ton, depending on the crew size, equipment, and procedures used.

Pavement Performance Models

Pavement roughness is a major factor that influences pavement ride quality and usually leads to rider discomfort, increased travel times, and higher operational cost for vehicle. Smoothness has been used as a measure of pavement performance and serviceability since road test conducted by American Association of State Highway Officials (AASHO). The present serviceability rating (PSR) concept was initiated and for practical purposes, the present serviceability index (PSI) was developed as a mean to determine performance from measurements of physical condition of the pavement *[59]*. The University of Michigan conducted a research project in Brazil in the 1980s which initiated the development of the international roughness index (IRI) *[60]*. IRI represents the vibration incurred by the vehicle due to the roughness of the pavement as a characteristic of the longitudinal profile of a traveled roadway and comprises a standardized roughness measurement. Generally, the measuring units for IRI are meter per kilometer or in. per mile *[61]*.

Over the years, researchers have successfully applied the IRI for modeling the smoothness of a pavement *[9], [62], [63], [64], [65]*. Surface age and traffic were used as predictor variables by Hein and Watt in an effort to built empirical prediction model for pavement performance [66]. Simple IRI prediction models using initial IRI (after some initial traffic loading), surface age, structural number, cumulative equivalent single axle load (ESAL), climatic factors were developed by Perera et al. and Ozby and Laub *[67], [68]*. Roughness progression in HMA overlay pavement shows distinct trends in similar climatic environments as suggested by Perera and Kohn *[69]*. A combination of field and experimental data was used by Prozzi and Madanat to develop pavement performance although in practice it is very difficult to get proper filed data with all maintenance information and accurately simulated experimental data *[70]*.

IRI models based on statistical analysis have been developed by the Long Term Pavement Performance (LTPP) program, M-E PDG, Mississippi and Washington Department of Transportation (DOT), and other state agencies *[71], [72], [73]*. All such models generally recognize that major factors contributing to the model can be divided into two parts: variables related to distresses like cracking, rutting, spalling and faulting; and variables related to distressless site factors such as age of pavement, structural number, traffic loading, precipitation, temperature, freezing index, cooling index, and thickness of pavement layers. Haider and Dwaikat initiated two separate models for pre-treatment performance and post treatment performance of pavement where post-treatment performance was also associated with performance jump or effectiveness of treatment *[74]*. To account for potential bias in the IRI model M-E PDG, Aguiar-Moya et al. have suggested joint random effect approach instead of ordinary least square method. Some researchers tried to overcome some of the limitations of regression analysis and used statistical approaches Fuzzy, Gray theories, and Neuro-Fuzzy reasoning to accommodate better performance models *[75], [76], [77]*. Khattak et al. had previously used only age as predictor variable to develop polynomial performance model *[78]*.

Cracking is one of the major forms of distress in composite pavement which hinders ride quality and usually leads to rider discomfort, increased travel times, and higher operational cost for vehicle *[59]*. In addition to inducing roughness, the penetration of water and other debris accelerate the rate of deterioration of HMA overlay and underlying PCC layer and reduce the pavement service life *[79]*. Composite pavement has HMA layer over PCC and exhibits the structural soundness along with pavement smoothness and noise reduction in the existing pavement. It also enhances pavement surface friction and increases structural integrity of the PCC layer. HMA layer also helps by reducing the temperature gradient in the PCC layer thus minimizing the effects of curling stress *[80]*. Composite pavement suffers mostly reflective cracking which results in transverse and longitudinal cracking as well as fatigue cracking *[79], [80], [81]*. In composite pavement, fatigue cracking occurs in the HMA overlay due to tensile strains in the bottom of the layer. Also, any fatigue cracking in PCC pavement can propagate upward in the HMA overlay. Various factors contribute to this such as type of material, vehicle loading patterns, climatic factors, temperature gradients, and so forth *[79], [80], [81]*. On the

other hand, transverse cracks in the HMA overlay are mainly reflective cracks. Such cracks occur due to differential movements in horizontal and vertical direction along existing joints and cracks in the PCC pavement. They are caused by the variation in temperature, moisture infiltration and heavy vehicle loading *[80], [81].* Longitudinal cracking are top-down cracks due to heavy vehicle loading. The longitudinal cracks can also be reflective cracks, which were existing in PCC pavements prior to the application of the HMA overlay.
Many studies have been conducted to address the cracking problem and predicting the cracking performance. In the early days, prediction models for cracks in pavements have tried to predict initiation and progression of cracking and also percent of area cracking using ESAL, structural number, and California bearing ration (CBR) values *[82].* Later, the World Bank model was developed from a comprehensive, factorially designed database of in-service pavements for initiation of cracking where mechanistic properties of pavement were used *[83], [84].* Rauhut et al. suggested sigmoid form of cracking and proposed a model to convert damage index (DI, a damage function) to percentage of area cracking percentage *[85].* Sigmoid or S-shaped curve model has been utilized in Texas Pavement Design System to capture the long-term behavior of pavements for fatigue, longitudinal and transverse cracking *[79].* Cracking models based on statistical analysis have been developed by Long Term Pavement Performance (LTPP) program, Mississippi and Washington Departments of Transportation and other state agencies *[71], [72], [73]*. Important explanatory variables used in these models are pavement distress characteristics, subgrade characteristics, traffic characteristics, mechanistic properties, and climatic factors.

Rutting is a surface depression in the wheel paths generally caused by truck tire pressures, axle loads, and traffic volume *[86]*. Longitudinal deviation of rut depth in the wheel path is a primary factor in the road roughness which affects serviceability and IRI (International roughness Index) *[87].* Pavement roughness influences pavement ride quality and usually leads to rider discomfort, increased travel times, and higher operational cost for vehicle. In the transverse direction of pavement, rutting along the wheel path hampers drainage characteristics and reduces runoff capability and cause hydroplaning and loss of friction *[88], [89]*. Longitudinal crack, which often occur in deep ruts, induces the penetration of water and other debris and accelerate the rate of deterioration of HMA overlay and underlying PCC layer and reduce the pavement service life *[88].*

Regarding rutting, it is commonly believed that rutting is a demonstration of two different mechanisms and is a combination of densification (change in volume) and repetitive shear deformation (lateral movement or plastic flow with no change in volume) *[90]*. Both densification and shear deformation are strongly influenced by traffic loading, pavement structure and pavement material properties. The climate has significant effect on rutting development, when the subgrade experiences seasonal variations and when the bituminous materials are subjected to high temperatures.

The provided models are applicable only within the range of the data used for the development of the model. These models need calibration when used out of their boundary conditions and often the form of the model has to be modified *[91]*. Like many other regions, the state of Louisiana has a variety of weather, traffic, and soil conditions. Louisiana falls under wet no-freeze zone according to LTPP database *[67]*. The climatic indices developed by LTPP like freezing index and annual number of freeze-thaw cycles are not applicable for Louisiana *[73]*. Furthermore, the Louisiana Department of Transportation and Development (DOTD) is in the process of developing an integrated and comprehensive PMS database that will not only include the pavement distresses but also the climatic and pavement history and inventory data. Such information is commonly used by most models *[46], [71]*. Timely rehabilitation and preservation of pavement systems are imperative to maximize benefits in terms of driver's comfort and safety, and spending of tax payers' dollars. DOTD's rehabilitation and preventive maintenance of flexible and composite pavements is accomplished using various treatment options including the following: replacement, structural (thick) overlay, non-structural (thin) overlays, crack sealing, chipseals, micro-surfacing, patching, full-depth concrete repair, and whitetopping *[92]*.

Treatment Cost Benefit Analysis

The NCHRP Report 523 by Peshkin et al. presented a methodology for the selection of the optimum timing for preventive maintenance treatments on rigid and flexible pavements based on the total benefits (TB) of the treatment *[9]*. The methodology calls for the selection of upper and lower cutoff values based on pavement condition or distress, distress index, or deduct points. The upper and lower cutoff values represent the range in pavement conditions or the range in time when preventive maintenance activities will be beneficial. The area between the upper and lower values and the performance curve represents the benefit as shown in Figure 5. Preventive maintenance activities conducted outside the two values are considered to be done too early or too late in the pavement service life to provide benefits. Total benefit of a treatment is quantified using the following procedure *[9]:*

1. The performance of the pavement section prior to preventive maintenance treatment must be known from the time of the previous construction or rehabilitation to the end of the pavements serviceable life. The area between the performance curve and the lower cutoff value (the do-nothing area) is then calculated.
2. The pavement performance after treatment must be estimated or predicted, from the time when the preventive maintenance is applied to the time when the pavement reaches the lower cutoff value as shown in Figure 6. The benefit area (the area between the two performance curves and the lower cutoff value shown in the figure) is then calculated.
3. The total benefit (TB) of the treatment is then calculated as the ratio of the benefit area to the do-nothing area as shown in Figures 7 and 8 and expressed in equation (5).

$$\text{TOTAL BENEFIT} = \text{TB} = \frac{\text{AREA}_{(\text{Benefit})}}{\text{AREA}_{(\text{Do-Nothing})}} \tag{5}$$

4. The benefit to cost ratio is then calculated as the ratio of the TB to the total treatment costs including user costs as stated in equation (6). The benefit to cost ratio is then normalized and expressed as the treatment effectiveness index (EI), which is defined by the ratio of a given benefit to cost ratio divided by the maximum possible benefit to cost ratio as expressed in equation (7).

$$\left(\frac{\text{Benefit}}{\text{Cost}}\right)_i = \frac{\text{TOTAL BENEFIT}_i}{\text{EUAC}_i} \tag{6}$$

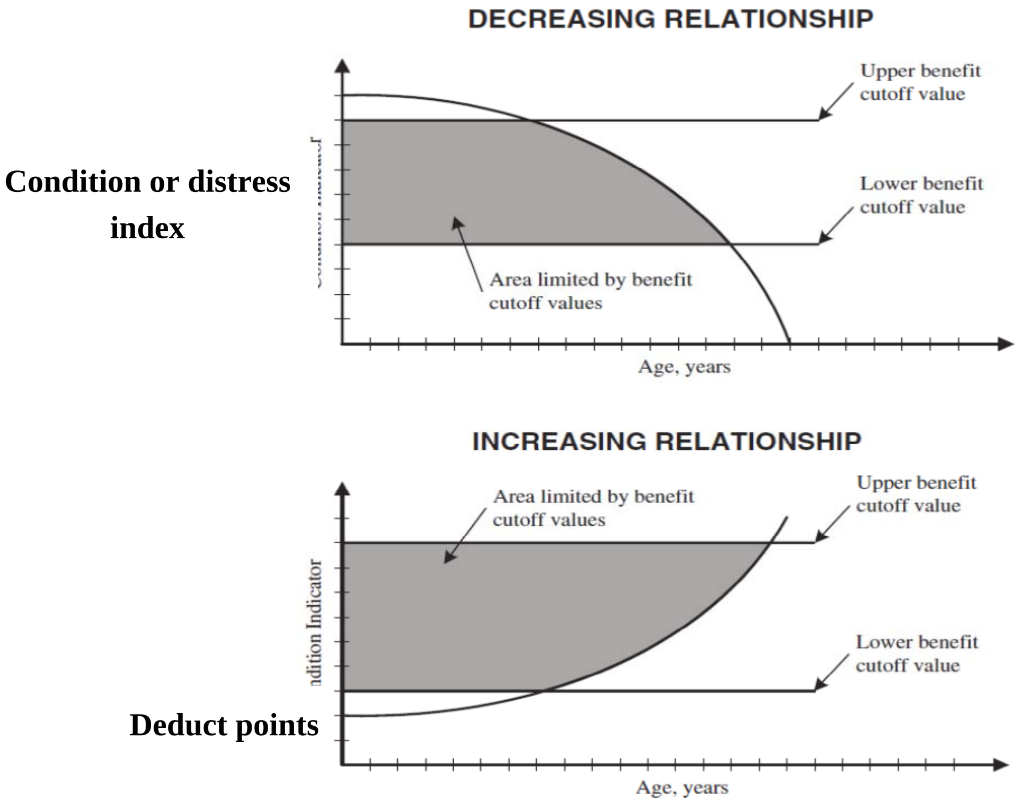


Figure 5

Benefit cutoff values based on distress index and deduct points *[9]*

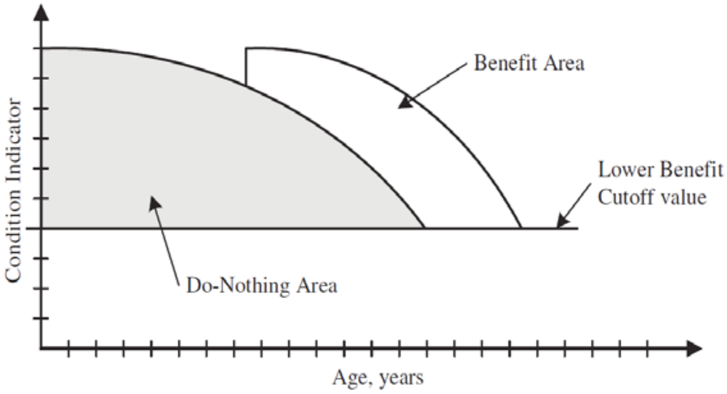


Figure 6

Preventive maintenance benefit area *[9]*

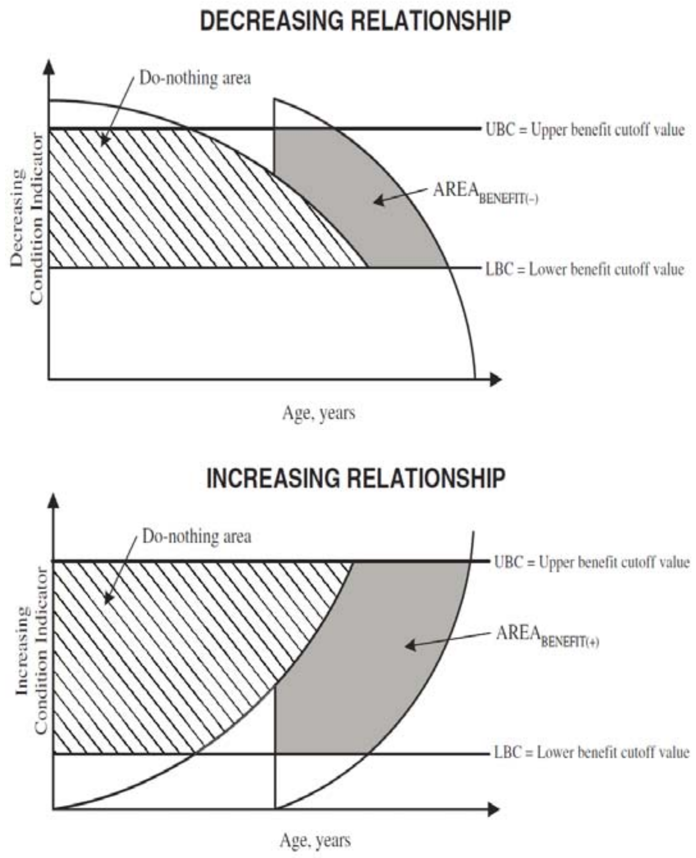


Figure 7

Total benefit areas *[9]*

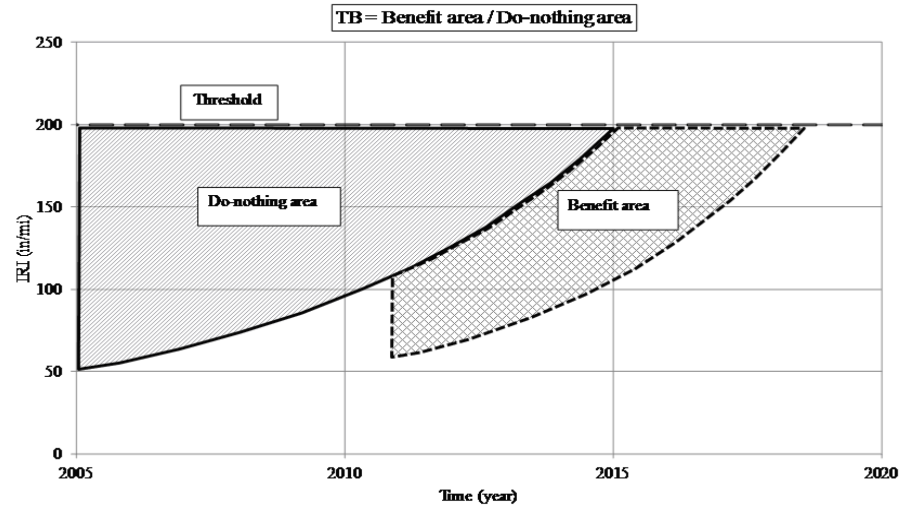


Figure 8
Schematic of the definition of total benefit (TB)

$$\mathrm{EI}_i = \left[\frac{\left(\frac{\text{Benefit}}{\text{Cost}}\right)_i}{\left(\frac{\text{Benefit}}{\text{Cost}}\right)_{\max}} \right] \times 100 \qquad (7)$$

Where,
i is the ith treatment timing scenario;
EUAC is the equivalent uniform annual cost;
EI is the effectiveness index; and
max is the maximum outcome among the “i" treatment timing scenarios.

In order to use the total benefit methodology, accurate data must be available for modeling both the do-nothing performance curve and the post-treatment performance curve. The former curve could be constructed based on the available time dependent pavement condition and distress data and extended to the upper or lower limits. The post-treatment performance curve however must be assumed by its entirety based on the average performance of the same treatment applied to different pavement projects. This reflects the sensitivity of the methodology to the available and assumed data. Hence, the only way to implement the methodology is to use network-level data or model to create the post-treatment performance curve and to complete the do-nothing performance curve. The network-level model(s) must be detailed enough and flexible to account for the various project-level inputs.

REFERENCES

1. Gransberg, D. and James, D.M.B. *Chipseal Best Practices.* Washington, D.C. NCHRP Synthesis of Highway Practice 342, Transportation Reserach Board, National Research Council, 2005.
2. Johnson, A.M. *Best Practices Handbook on Asphalt Pavement Maintenance.* Minnesota Minnesota T2/LTAP Program, Center for Transportation Studies, 2000. University of Minnesota Report No. 2000-04.
3. Caltrans. *Maintenance Technical Advisory Guide Volume 1: Flexible Pavement Preservation, 2nd ed.* Sacramento, CA State of California Department of Transportation, 2008.
4. Ohio DOT. *Pavement Preventive Maintenance Program Guidelines.* Ohio The Office of Pavement Engineering Report, 2001.
5. Shuler, S. and Lord, A. *Determining Time to Uncontrolled Trafficking After Chipseal Construction.* Newport Beach, CA Compendium of Papers from the First International Conference on Pavement Preservation, 2010. 189-201. Print.
6. Nevada Department of Transportation. *Exploring Alternative Strategies for the Rehabilitation of Low-Volume Roads in Nevada.* Carson City, Nevada Final Management Report. Nevada Department of Transportation, 2008.
7. Davis, L. and Miner, J. *Chipseal ing Over Paving Fabric in Various Climatic Conditions.* Newport Beach, CA Compendium of Papers from the First International Conferance on Pavement Preservation, 2010. 331-350. Print.
8. Maher, M., et al. *Context Sensitive Roadway Surfacing Selection Guide.* s.l. Federal Highway Administration Central Federal Lands Highway Division, 2005. FHWA-CFL/TD-05-004a.
9. Peshkin, D.G., Hoerner, T.E. and Zimmerman, K.A. *Optimal Timing of Pavement Preventive Maintenance Treatment Applications.* Washington, D.C. Transportation Research Board, National Research Council, 2004. NCHRP Report No 523.
10. Wade, M., DeSombre, R.l and Peshkin, D.G. *High Volume/High Speed Asphalt Roadway Preventive Maintenance Surface Treatments.* s.l. South Dakota Department of Transportation, 2001. Report No. SD99-09.
11. Romero, P and Anderson, D.I. *Life Cycle of Pavement Preservation Seal Coats.* s.l. Utah Department of Transportation Research Division, 2005. Report No. UT-04.07.
12. Jahren, C.T. and Chen, D. *Long-Term Performance of Cold In-Place Recycled Asphalt Roads.* Iowa Proceedings of the 2005 Mid-Continent Transportation Research Symposium Ames, 2005.

13. Liu, L., Hossain, M. and Miller, R. *Life of Chipseal on Kansas Highways.* Newport Beach, CA Compendium of Papers from the First International Conference on Pavement Preservation, 2010. 331-350. Print.
14. Bolander, P.W. *Seal Coat Options: Taking Out the Mystery.* Kansas City, Missouri First National Conference on Pavement Preservation, 2005. Transportation Research Circular No. E-C078.
15. Geoffroy, D.N. *Cost-Effective Preventive Pavement Maintenance.* Washington, D.C. Transportation Research Board, National Research Council, 1996. NCHRP Synthesis of Highway Practice 223.
16. Hicks, G.R., Seeds, S.B. and Peshkin, D.G. *Selecting a Preventive Maintenance Treatment for Flexible Pavements.* s.l. Prepared for Foundation of Pavement Preservation, 2000.
17. Pierce, L. M., et al. *Utilization of Bituminous Surface Treatments for Maintaining Asphalt Concrete Pavements Due to Restricted Budgetary Constraints in Washington State* . Newport Beach, CA Compendium of Papers from the First International Conference on Pavement Preservation., 2010. 73-84. Print.
18. Reigle, J. *Development of an Integrated Project-Level Pavement Management Model Using Risk Analysis.* s.l. Ph.D. dissertation, University of West Virginia, 2000.
19. Brown, N. R. *Extending Pavement Life by Forestalling Crack Reflection.* Newport Beach, CA Compendium of Papers from the First International Conferance on Pavement Preservation, 2010. 331-350. Print.
20. Hicks, G.R., Fee, F. and Moulthrop, J.S. *Experiences With Thin and Ultra Thin HMA Pavements in the United States.* Sydney, Australia Australian Asphalt Pavement Association International Conference, 2000.
21. Outcalt, W. *SHRP Chipseal . Colorado Department of Transportation Research Branch.* s.l. Colorado Department of Transportation Research Branch, 2001. Report No. CDOT-DTD-R-2001-20.
22. Jahren, C.T. and Bergerson, K. *Thin Maintenance Surfaces: Phase One Report.* s.l. Iowa Department of Transportation and the Center for Transportation Research and Education, CRTE Management Project 97-14. Final Report, 1999.
23. Yut, I., Nener-Plante, D. and Zofka, A. *Case Study on Perpetual Flexible Pavement in Connecticut.* Newport Beach, CA Compendium of Papers from the First International Conference on Pavement Preservation, 2010. 519-532. Print.

24. Wu, Z., et al. *Performance Evaluation of Various Rehabilitation and Preservation Treatments.* Washington, D.C U.S. Department of Transportation and Federal Highway Administration, 2010.
25. Cuelho, E., Mikwa, R., and Akin, M. *Preventive Maintenance Treatments of Flexible Pavements: A Synthesis of Highway Practice. Prepared for . Report No. .* Montana State University – Bozeman Montana Department of Transportation Research. Section by the Western Transportation Institute, 2006. Report No. FHWA/MT-06-009/8117-26.
26. Johnson, E. and Olson, R. *Investigation of Winter Pavement Tenting.* St. Paul, MN Prepared for Minnesota Department of Transportation by Mn/DOT Office of Materials, 2008. Report No. MN/RC 2008-03.
27. Federal Highway Administration. *Materials and Procedures for Sealing and Filling Cracks in Asphalt-Surfaced Pavements.* Washington, DC U.S. Department of Transportation, 1999. FHWA-RD-99-147.
28. Kreis, D., O'Connell, L. and Howell, B. *Long-Term Maintenance Needs Planning.* Frankfort, KY Kentucky Transportation Cabinet by the Kentucky Transportation Center, 2005. Report No KTC-05-25/RSS8-02-IF.
29. B.T. Bellner & Associates. *Effectiveness of the Capital Preventive Maintenance Program Prepared for Michigan Department of Transportation.* 2001.
30. Gransberg, D. *Microsurfacing.* Washington, D.C. Transportation Research Board, National Research Council,, 2010. NCHRP Synthesis of Highway Practice 411.
31. International Slurry Surfacing Association (ISSA). *Recommended Performance Guidelines for Micro-Surfacing. Document ISSA A143 (revised).* 2005. Document ISSA A143 (revised).
32. Smith, R.E. and Beatty, C.K. *Microsurfacing Usage Guidelines.* Washington, D.C. Transportation Research Board, National Research Council, 1999. Transportation Research Record 1680.
33. Johnson, N., Wood, T.J. and Olson, R.C. *Flexible Slurry– Microsurfacing System for Overlay Preparation.* Washington, D.C. Transportation Research Board of the National Academies, 2007. Journal of the Transportation Research Board, No. 1989.
34. Kazmierowski, T.J., et al. *Effectiveness of High Performance Thin Surfacings in a Wet-Freeze Environment.* Washington, D.C. Proceedings: 72nd Annual Meeting of the Transportation Research Board, 1993.
35. Labi, S. and Sinha, K. *The Effectiveness of Maintenance and Its Impact on Capital Expenditures.* West Lafayette, Indiana s.n., 2003. Technical Report FHWA/IN/JTRP-2002-27.

36. Peshkin, D.G. and Hoerner, T.E. *Pavement Preservation: Practices, Research Plans, and Initiatives.* Washington, D.C. Transportation Research Board, National Research Council, 2005. NCHRP Project 20-07, Task 184, Final Report.
37. McHattie, R.L. and Elieff, J.A. *Cost-Effective Rut Repair Methods Elieff Engineering and Consulting Group.* s.l. Prepared for Alaska DOT&PF Research and Technology Transfer, 2001. FHWA-AK-RD-01-04.
38. Labi, S., et al. *Long-term Benefits of Microsurfacing Applications in Indiana – Methodology and Case Study.* Washington, D.C. Proceedings: 85th Annual Meeting of the Transportation Research Board, 2006.
39. Bausano, J.P., Chatti, K. and Williams, R.C. *Determining Life Expectancy of Preventive Maintenance Fixes for Asphalt-Surfaced Pavements.* Washington, D.C. Transportation Research Board of the National Academies, 2004. Transportation Research Record: Journal of the Transportation Research Board, No. 1866.
40. Lyon, C. and Persaud, B. *Safety Effects of Targeted Program to Improve Skid Resistance.* Washington, D.C. Transportation Research Board of the National Academies, 2008. Transportation Research Record: Journal of the Transportation Research Board, No. 2068.
41. Watson, D. and Jared, D. *Georgia Department of Transportation's Experience with Microsurfacing.* Washington, D.C Transportation Research Board of the National Academies, 1998. Transportation Research Record: Journal of the Transportation Research Board, No. 1616.
42. Temple, W., et al. *Performance of Louisiana's Chipseal and Microsurfacing Program.* Washington, D.C. Transportation Research Board of the National Academies, 2002. Transportation Research Record: Journal of the Transportation Research Board, No. 1795.
43. Chehovits, J. and Galehouse, L. *Energy Usage and Greenhouse Gas Emissions of Pavement Preservation Processes for Asphalt Concrete Pavements.* Newport Beach, CA Proceedings of the 1st International Conference on Pavement Preservation, 2010.
44. Gatchalian, D., et al. *Characterization of Aggregate Resistance to Degradation in Stone Matrix Asphalt Mixes.* Washington, D.C. Proceeding:85th Annual Meeting of the Transportation Research Board, 2006.
45. Hein, D. and Croteau, J.M. *The Impact of Preventive Maintenance Programs on the Condition of Roadway Networks.* Quebec City, Quebec. Proceedings: 2004 Annual Conference of the Transportation Association of Canada, 2004.

46. Zhou, F. and Scullion, T. *Mix Design, Construction, and Performance of a Thin HMA Overlay on Pumphrey Drive, Fort Worth, TX.* Austin, TX Prepared for Texas Department of Transportation by Texas Transportation Institute, 2008. Report No. FHWA/TX-09/5-5123-01-2.
47. Chou, E. Y., Datta, D. and Pulugurta, H. *Effectiveness of Thin Hot Mix Asphalt Overlay on Pavement Ride and Condition Performance.* Toledo, OH Prepared for Ohio Department of Transportation by the University of Toledo., 2008. Report No. FHWA/OH-2008/4.
48. Hein, D. K. and Rao, S. *Rational Procedures for Evaluating the Effectiveness of Pavement Preservation Treatments.* Newport Beach, CA Compendium of Papers from the First International Conference on Pavement Preservation, 2010. 117-130. Print.
49. Winkleman, T. J. *Whitetopping Construction and Early Performance in Illinois.* Springfield, IL Performed by Illinois Department of Transportation Bureau of Materials and Physical Research, 2002. Report No. FHWA/IL/PRR 144.
50. Rasmussen, R.O. and Rozycki, D.K. *Thin and Ultra-Thin Whitetopping – A Synthesis of Highway Practice.* Washington, D.C. Transportation Research Board, 2004. NCHRP Synthesis 338.
51. Wen, H., Li, X. and Martono, W. *Performance Assessment of Wisconsin's Whitetopping and Ultra-thin Whitetopping Projects.* Madison, WI Wisconsin Department of Transportation Division of Transportation Infrastructure Development, 2010. Report No. 10-03.
52. Mowris, S. *Whitetopping Restores Air Traffic at Spirit of St. Louis.* s.l. Concrete Construction,, 1995.
53. Silfwerbrand, J. *Whitetoppings—Swedish Field Tests and Recommendations.* Indianapolis, Ind Proceedings of the 6th International Purdue Conference on Concrete Pavement Design and Materials for High Performance, Vol. 2, 1997.
54. Burnham, T. R. *Forensic Investigation Report for MN/ROAD Ultrathin WhitetoppingTest Cells 93, 94, and 95.* St. Paul, MN. Performed by Minnesota Department of Transportation Office of Materials, 2005. Report No. MN/RC - 2005-45.
55. Cable, J.K., Edgar, L.E. and Anderson, D.R. *Ultra-Thin Portland Cement Concrete Overlay Extended Evaluation.* Ames, IA. Performed by Iowa State University Department of Civil, Construction and Environmental Engineering for Iowa Highway Research Board Iowa Department of Transportation, 2005. Iowa DOT Project TR-432.

56. FHWA. Full Depth Repair. *Federal Highway Administration.* [Online] U.S. Department of Transportation, 07 4, 2011. [Cited: 7 4, 2011.] http://www.fhwa.dot.gov/pavement/concrete/full1.cfm.
57. Caltrans. *Maintenance Technical Advisory Guide Volume II - Rigid Pavement Preservation, 2nd ed.,.* Caltrans, Sacramento State of California Department of Transportation, 2008.
58. Stoffels, S. M., Kilareski, W.P and Cady, P.D. *Evaluation of Concrete Pavement Rehabilitation in Pennsylvania,"* West Lafayette, IN. Proceedings of the Fifth International Conference on Concrete Pavement Design and Rehabilitation, Purdue University, 1993.
59. Titus-Glover, Leslie and Darter, Michael I. *Guidelines for Improving Full-Depth Repair of PCC Pavements in Wisconsin.* Champaign, IL Applied Research Associates, Inc., 2008.
60. Gillespie, T. D. *Effects of heavy-vehicle characteristics on pavement response and performnce.* Washington, D.C. National Cooperative Highway Research Program, Res. Rep. No. 353, Transportation, 1993.
61. Zhou, G., Wang, L., and Lu, Y. *IRI MODEL ENHANCEMENT FOR FLEXIBLE PAVEMENT DESIGN USING LTPP DATA.* Washington, D.C. Transportation Research Board, 2008.
62. Shirazi, H., et al.*Confidence Level and Efficient Sampling Size of Roughness Measurements for Pavement Management in Maryland.*Transportation Research Record: Journal of the Transportation Research Board, Vol. 2153, pp. 114-120, 2010.
63. Zimmerman, K. A. and Peshkin, D. G. *Pavement Management Perspective on Integrating Preventive Maintenance into a Pavement Management System.*Transportation Research Record: Journal of the Transportation Research Board, Vol. 1827, pp. 3-9. 2003.
64. Kargah-Ostadi, Nima, S., Shelley, M. and Tabatabaee, N. *Network-Level Pavement Roughness Prediction Model for Rehabilitation Recommendations.* Transportation Research Record: Journal of the Transportation Research Board, Vol. 2155, pp. 124-133, 2010.
65. Lu, P. and Tolliver, D. *Pavement Pre- and Post-Treatment Performance Models Using LTPP Data.* Journal of the Transportation Research Forum, Vol. 51, pp. 67-81, 2012.

66. Hein, D., and Watt, D. *Municipal Pavement Performance Prediction based on Pavement Condition Data.* Calgary, Alberta. Proceedings of the Annual Conference of the Transportation Association of Canada, 2005.
67. Perera, R.W., Byrum, C. and Kohn, S.D. *Investigation of Developement of Pavement Roughness.* U.S. Department of Transportation. McLean, Virginia FHWA,, FHWA-RD-97-147, 1998.
68. Ozbay, K. and Laub, R. *Models for Pavement Deterioration Using LTPP.* Washington, D.C. New Jersey Department of Transportation, Division of Research and Technology and U.S. Department of Transportation Federal Highway Administration, 2001.
69. Perera, R.W. and Kohn, S.D. *LTPP Data Analysis: Factors Affecting Pavement Smoothness.* Washington, D.C. National Cooperative Highway Research Program Project 20-50 (8/13), Transportation Research Board., 2001.
70. Prozzi, J.A. and Madanat, S.M. *Development of Pavement Performance Models by Combining Experimental and Field Dat* Journal of Infrastructure Systems, Vol. 10, pp. 9-22.*,* 2004.
71. ARA, Inc., ERES Division. *Guide for Mechanistic-Empirical Design OF NEW AND REHABILITATED PAVEMENT STRUCTURES CHAPTER 4. DESIGN OF NEW AND RECONSTRUCTED RIGID PAVEMENTS.* Champaign, Illinois National Cooperative Highway Research Program, 2001.
72. George, K. P. *MDOT Pavement Management System: Prediction Models and Feedback System.* Jackson, MS 39215-1850 Mississippi Department of Transportation, 2000.
73. Jackson, N. and Puccinelli, J. *Long-Term Pavement Performance (LTPP) Data Analysis Support National Pooled Fund Study Tpf-5(013).* McLean, VA Federal Highway Administration, 2006.
74. Haider, S.W., and Dwaikat, M. B.*Estimating Optimum Timing for Preventive Maintenance Treatments to Mitigate Pavement Roughness.* 2235, 2011. Transportation Research Record: Journal of the Transportation Research Board, pp. 43-53.
75. Aguiar-Moya, J., Prozzi, J. and Smit, A. de Fortier.*Mechanistic-Empirical IRI Model Accounting for Potential Bias.* Journal of Transportation Engineering, Vol. 137, pp. 297-304, 2011.
76. Wang, K. C. P. and Li, Q. *Pavement Smoothness Prediction Based on Fuzzy and Gray Theories.* Computer-Aided Civil and Infrastructure Engineering, Vol. 26, pp. 69-76, 2011.

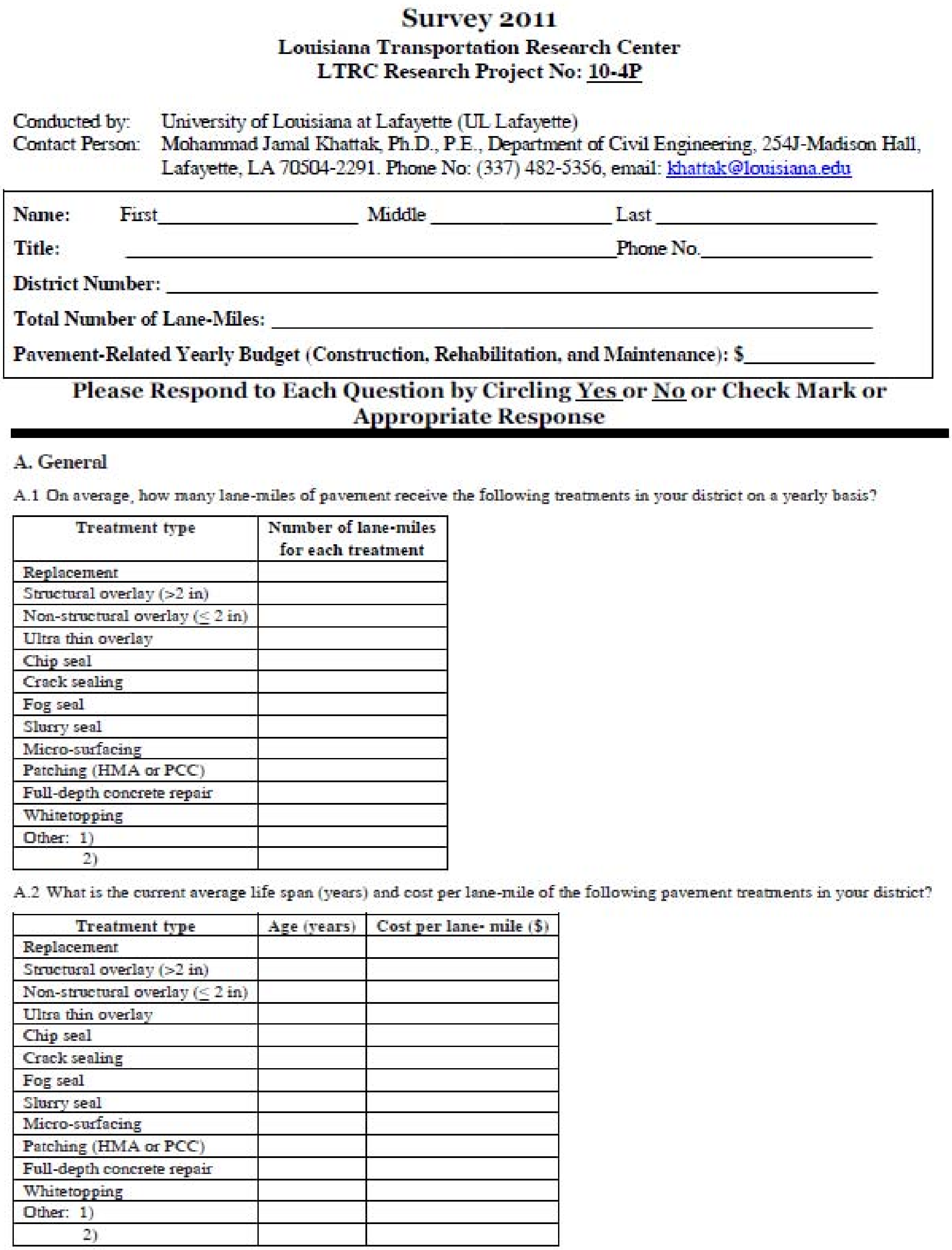
77. Bianchini, A., and Bandini, P. *Prediction of Pavement Performance through Neuro-Fuzzy Reasoning.* Computer-Aided Civil and Infrastructure Engineering, Vol. 25, pp. 39-54, 2010.
78. Khattak, M. J., et al. *Rigid and composite pavement index-based performance models for network pavement management system in the state of Louisiana.* International Journal of Pavement Engineering, pp. 1-17, 2012.
79. Lytton, R. L., et al. *Models for Predicting Reflection Cracking of Hot-Mix Asphalt Overlays.* Texas Transportation Institute, Texas A&M University, Texas Transportation Institute. Washington, D.C. NCHRP Report 669, Transportation Research Board, 2010.
80. Flintsch, G. W., Diefenderfer, B. K. and Nunez, O. *Composite Pavement Systems: Synthesis of Design and Construction Practices.* Richmond, VA 23219 Virginia Department of Transportation, 2008. VTRC 09-CR2.
81. Dave, E. V. and Buttlar, W. G. *Thermal reflective cracking of asphalt concrete overlays.* International Journal of Pavement Engineering, Vols. Vol. 11, No. 6, pp. 477–488. 2010.
82. Queiroz, C.A.V. and Hudson, W. R. *Improved Pavement Performance Relationships in Brazil.* Ann Arbor, Michigan Fifth International Conference on the Structural Design of Asphalt Pavements, Proceedings, Vol. 1, The University of Michigan,, 1982.
83. Paterson, W.D.O. *Road Deterioration and Maintenance Effects – Models forPlanning and Management. Highway Design and Maintenance Standards Series.* Baltimore and London The Johns Hopkins University Press, 1987.
84. Rauhut, J.B. and Kennedy, T. W. *Characterizing Fatigue Life of Asphalt Concrete Pavements.* Washington, D.C. TRB, National Research Council, Vol. Transportation Research Record 888, 1982.
85. Rauhut, J. B., et al. *Damage Functions for Rutting, Fatigue Cracking, and Loss of Serviceability in Flexible Pavements.* Washington, D.C. TRB, National Research Council, Vol. Transportation Research Record 943, 1983.
86. WHITE, T. D., et al. *Contributions of Pavement Structural Layers to Rutting of Hot Mix Asphalt Pavements.* Washington, D.C. Transportation Research Board. NCHRP REPORT 468, 2002.
87. ARA, Inc., ERES Division. *APPENDIX GG-1: CALIBRATION OF PERMANENT DEFORMATION MODELS FOR FLEXIBLE PAVEMENTS.* Washington, D.C.

National Cooperative Highway Research Program. Transportation Research Board, 2004.

88. Oscarsson, E. *Evaluation of the Mechanistic–Empirical Pavement Design Guide model for permanent deformations in asphalt concrete.* No. 1, s.l. Taylor & Francis, International Journal of Pavement Engineering, Vols. Vol. 12,, pp. 1-12, 2011.
89. Luo, R. and Prozzi, J. A. *Development of a Pavement Rutting Model from Long-Term Pavement Performance Data.* s.l. TRB Committee AFS50, 2008.
90. Hu, S., Zhou, F. and Scullion, T. *Development, Calibration, and Validation of a New M-E Rutting Model for HMA Overlay Design and Analysis.* ASCE, Journal of Materials in Civil Engineering, Vol. Vol. 23, pp. 89-99, 2011.
91. Ahammed, M. Alauddin and Tighe, S. L.*Statistical Modeling in Pavement Management: Do the Models Make Sense?* Transportation Research Record: Journal of the Transportation Research Board, Vol. 2084, pp. 3-10, 2008.
92. Khattak, M. J., et al. *A Review of the Pavement Management System of the State of Louisiana-Phase I.*, Transportation Research Record: Journal of the Transportation Research Board, Vol. 2084, pp. 18-27, 2008.

APPENDIX B

District Survey Questionnaire of Pavement Treatment Practices



Survey 2011

Louisiana Transportation Research Center

LTRC Research Project No: 10-4P

Conducted by: University of Louisiana at Lafayette (UL Lafayette)
Contact Person: Mohammad Jamal Khattak, Ph.D., P.E., Department of Civil Engineering, 254J-Madison Hall, Lafayette, LA 70504-2291. Phone No: (337) 482-5356, email: khattak@louisiana.edu

Name: First____________ Middle ____________ Last ____________
Title: ________________________ Phone No.____________
District Number: ________________________
Total Number of Lane-Miles: ________________________
Pavement-Related Yearly Budget (Construction, Rehabilitation, and Maintenance): $____________

Please Respond to Each Question by Circling Yes or No or Check Mark or Appropriate Response

A. General

A.1 On average, how many lane-miles of pavement receive the following treatments in your district on a yearly basis?

Treatment type	Number of lane-miles for each treatment
Replacement	
Structural overlay (>2 in)	
Non-structural overlay (≤ 2 in)	
Ultra thin overlay	
Chip seal	
Crack sealing	
Fog seal	
Slurry seal	
Micro-surfacing	
Patching (HMA or PCC)	
Full-depth concrete repair	
Whitetopping	
Other: 1)	
2)	

A.2 What is the current average life span (years) and cost per lane-mile of the following pavement treatments in your district?

Treatment type	Age (years)	Cost per lane- mile ($)
Replacement		
Structural overlay (>2 in)		
Non-structural overlay (≤ 2 in)		
Ultra thin overlay		
Chip seal		
Crack sealing		
Fog seal		
Slurry seal		
Micro-surfacing		
Patching (HMA or PCC)		
Full-depth concrete repair		
Whitetopping		
Other: 1)		
2)		

A.3 What percentages of the following pavement treatments are done by the District forces? Rate your experience with the performance of the treatments done by contractors.

Treatment type	Percent Work by the District forces	Contractor		
		Good	Fair	Poor
Replacement				
Structural overlay (>2 in)				
Non-structural overlay (≤ 2 in)				
Ultra thin overlay				
Chip seal				
Crack sealing				
Fog seal				
Slurry seal				
Micro-surfacing				
Patching (HMA or PCC)				
Full-depth concrete repair				
Whitetopping				
Other: 1)				
2)				

A.4 Do you use treatments that are not listed in the above tables? If yes, please write the treatments on the lines below.

1.____
2.____
3.____
4.____
5.____

B. Pavement and Mixture Design

B.1 Does your district design pavement treatment mixes? ☐ Yes ☐ No
B.2 Does your District design pavement treatment thickness? ☐ Yes ☐ No

If you answered no to B1 and B2, please skip to Question No. C.1

B.3 What method do you use in the design of the following treatments? (Please check all that apply)

Treatment type	AASHTO	In-house experience	Others
Replacement			
Structural overlay (>2 in)			
Non-structural overlay (≤ 2 in)			
Whitetopping			
Other: 1)			
2)			

B.4 What mix design procedure do you specify for the following PCC treatments? (Please check all that apply)

Treatment type	Hot Mix Asphalt (HMA)			Concrete		
	Marshall	Superpave	Other	Portland Cement Association (PCA)	American Concrete Institute (ACI)	Other
Replacement						
HMA overlay (>2 in)						
HMA overlay (≤ 2 in)						
PCC bonded overlay						
PCC unbonded overlay						
Other: 1)						
2)						

B.5 What mix design procedure do you specify for the following HMA treatments? (Please check all that apply)

Treatment type	**HMA**			**Concrete**		
	Marshall	**Superpave**	**Others**	**PCA**	**ACI**	**Other**
Replacement						
HMA structural overlay (>2 in)						
HMA non-structural overlay (≤ 2 in)						
Whitetopping						
Other: 1)						
2)						

C. Project Scoping Process

C.1 Do you utilize the PMS Data in your project scoping process? ☐ Yes ☐ No

C.2 What do you use to evaluate the existing pavement conditions? (Please check all that apply)

Pavement surface condition data

☐ Distress data such as roughness, rutting, cracking, etc.
☐ Composite pavement index
☐ Visual survey
☐ Distress index (DI)
☐ Remaining service life (RSL)
☐ Do not evaluate existing conditions
☐ Other method, please specify: ______________________________

Forensic investigation

☐ Destructive testing (coring, density, modulus, etc)
☐ Nondestructive testing (FWD, etc.)
☐ Other method, please specify: ______________________________

C.3 What is/are the major reasons for your district's decision to treat pavements? (Please check all that apply)

☐ Improve ride quality
☐ Improve skid resistance
☐ Retard distress propagation (cracking)
☐ PMS recommendations
☐ Improve structural capacity
☐ Eliminate surface rutting
☐ Provide a wearing surface
☐ Political
☐ Other reasons, please specify: ______________________________

C.4 What percent of the district's yearly budget is spent on the following treatment categories?

Treatment category	**% of budget**
Replacement	
Rehabilitation	
Preventive maintenance	
Routine maintenance	

C.5 What are the "trigger values" in your decision-making process? If using RSL, please skip down to Question No. C.6

Treatment type	**Functional and safety trigger**			**Structural trigger**				
				Cracking			**Rut depth (inch)**	**Faulting (inch)**
	IRI (in/mile)	**Skid number**	**Corrugated area (ft^2)**	**Number of cracks**	**Length of cracks**	**Cracked area (ft^2)**		
Replacement								
Structural overlay (> 2 in)								
Non-structural overlay (≤ 2 in)								
Ultra thin overlay								
Chip seal								
Crack sealing								
Fog seal								
Slurry seal								
Micro-surfacing								
Patching (HMA or PCC)								
Full-depth concrete repair								
Whitetopping								
Other: 1)								
2)								

C.6 If using the PMS RSL value (which is currently based on roughness), what is the trigger RSL value at which you perform each of the following treatment types?

Treatment type	RSL (years)
Replacement	
Structural overlay (> 2 in)	
Non-structural overlay (≤ 2 in)	
Ultra thin overlay	
Chip seal	
Crack sealing	
Fog seal	
Slurry seal	
Micro-surfacing	
Patching (HMA or PCC)	
Full-depth concrete repair	
Whitetopping	
Other: 1)	
2)	

C.7 What types of pre-treatment are applied for the pavement rehabilitation or preservation projects? (Please check all that apply)

Treatment type	Pre-treatment Application								
	Crack seal	Fog seal	Diamond grinding	Milling		Cold patch	Patching	Rubblization	Other
				Continuous	Spot				
Structural overlay (> 2 in)									
Non-structural overlay (≤ 2 in)								N/A	
Ultra thin overlay								N/A	
Chip seal		N/A	N/A					N/A	
Crack sealing	N/A	N/A	N/A	N/A				N/A	
Fog seal	N/A	N/A	N/A	N/A				N/A	
Slurry seal		N/A	N/A					N/A	
Micro-surfacing			N/A	N/A				N/A	
Whitetopping									
Other: 1)									
2)									

N/A: Not Applicable

D. Traffic

D.1 What traffic control measures are typically used for each treatment type?

Treatment type	Traffic control						
	Reduced speed	Pilot vehicles	Detour	Interim pavement marking and devices	Temporary traffic control devices (traffic light)	Flaggers	Other, please specify
Structural overlay (>2 in)							
Non-structural overlay (≤ 2 in)							
Ultra thin overlay							
Chip seal							
Crack sealing							
Fog seal							
Slurry seal							
Micro-surfacing							
Patching (HMA or PCC)							
Full-depth concrete repair							
Whitetopping							
Other: 1)							
2)							

D.2 Please write the traffic volume at which the following treatments are <u>not</u> performed?

Treatment type	Traffic volume (ADT)
Replacement	
Structural overlay (> 2 in)	
Non-structural overlay (≤ 2 in)	
Ultra thin overlay	
Chip seal	
Crack sealing	
Fog seal	
Slurry seal	
Micro-surfacing	
Patching (HMA or PCC)	
Full-depth concrete repair	
Whitetopping	
Other: 1)	
2)	

E. Contracting and Costs

E.1 What is the elapsed time (in months) between pavement project identification, design, and construction for the following two groups of treatments?

a. Rehabilitation treatments such as structural overlay (> 2 in)

Elapsed time to design_______________, To construction_________________

b. Preventive pavement treatments (such as non-structural overlay (≤ 2 in), chip seal, micro-surfacing, etc.)

Elapsed time to design_______________, To construction_________________

E.2 How many contractors typically bid on the listed jobs?

a. Structural pavement treatments such as structural overlay (>2 in) ☐ 1–3 ☐ 4–6 ☐ 7–9 ☐ Over 10

b. Preventive maintenance such as non-structural overlay (≤ 2 in), chip seal, micro-surfacing, etc.
☐ 1–3 ☐ 4–6 ☐ 7–9 ☐ Over 10

E.3 Do you feel that an adequate number of experienced contractors bid on your jobs? ☐ Yes ☐ No

E.4 What is your typical construction season? (Please check all that apply)

Treatment type	Construction season				
	Fall	Winter	Spring	Summer	Entire year
Replacement					
Structural overlay (> 2 in)					
Non-structural overlay (≤ 2 in)					
Ultra thin overlay					
Chip seal					
Crack sealing					
Fog seal					
Slurry seal					
Micro-surfacing					
Patching (HMA or PCC)					
Full-depth concrete repair					
Whitetopping					
Other: 1)					
2)					

E.5 Does your district use Life-Cycle Cost Analysis (LCCA) as a part of the decision process for selecting pavement type?

☐ Yes ☐ No

If yes, please answer the following questions. If no, please proceed to section F below.

a. Do you use any specialized software for LCCA? If yes, what software?____________________________________

b. Does your district include User Costs in the analysis? If yes, in what ways does it consider it? __________________

c. What discount rate is used and how is it determined? ____

d. What analysis period is used? (If not a fixed value, please explain briefly) __________________________________

e. What is the initial performance life assigned for reconstructed flexible and rigid pavement? ____________________

f. What treatment types do you define as maintenance? As rehabilitation?______________________________________

g. Does your district use salvage value or remaining service life (RSL) value in its LCCA calculations? ____________

h. Does your district have any guidelines or policies regarding the pavement treatment selection process? ___________

i. What are your decision criteria when pavement LCCA values for asphalt and concrete are very similar? ___________

F. Performance and Evaluation

F.1 Which factors do you feel are the most important in minimizing pavement defects and extending the life of your pavement treatments? (Please check the 3 most important factors)

☐ Construction procedure
☐ Better aggregates
☐ Underlying structure
☐ Moisture damage
☐ Design method
☐ Quality control
☐ Maintenance spending
☐ Other:_________________________
☐ Better binder
☐ Traffic
☐ Friction loss

F.2 Please rank the dominant distress types occurring after application of each of the following treatments (a ranking of 1 is the most dominant).

Treatment type	Distress type									
	Pothole	**Bleeding**	**Corrugation**	**Raveling**	**Alligator cracks**	**Transverse cracks**	**Longitudinal cracks**	**Rutting**	**Faulting**	**Corner break**
Replacement										
Structural overlay (> 2 in)										
Non-structural overlay (≤ 2 in)										
Ultra thin overlay										
Chip seal										
Crack sealing										
Fog seal										
Slurry seal										
Micro-surfacing										
Patching (HMA or PCC)										
Full-depth concrete repair										
Whitetopping										

F.3 In comparison to the ride quality before the application of treatments, what is the ride quality after application of the following treatments?

Treatment type	Ride quality		
	Better	Same	Worse
Replacement			
Structural overlay (> 2 in)			
Non-structural overlay (≤ 2 in)			
Ultra thin overlay			
Chip seal			
Crack sealing			
Fog seal			
Slurry seal			
Micro-surfacing			
Patching (HMA or PCC)			
Full-depth concrete repair			
Whitetopping			
Other: 1)			
2)			

F.4 Do you subcontract the quality assurance (QA)?

☐ Yes ☐ No

F.5 Please list your district's projects that have received any of the above pavement treatments during time period 2001-2005. (Attach a separate sheet, if required). This list is key for the treatment performance modeling as a part of this research study.

Treatment type	Year	Project number	Control section	Route	Direction	Log-mile		Additional important information
						Begin	End	

F.6 If there is anything that you would like to add that was not covered in this questionnaire that you feel would benefit this pavement treatments study, please write your comments below:

____

____

____

____

____

____

THANK YOU FOR SUPPORTING THIS IMPORTANT EFFORT

Please respond by February 14, 2011

APPENDIX C

Distribution of Pavement Treatment Projects with Good History and Pavement Performance

Table 1
Distribution of selected projects based on treatment and pavement type for each district with 3 BT and 3 AT data points

Treatment Types	Pavement Type	District 02				District 03				District 04			
		No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted
Overlay	ASP	30	1,106	734	66	39	1,623	911	56	40	1,659	1,078	65
	COM	14	482	169	35	15	233	119	51	13	447	314	70
	JCP	3	113	36	32	10	188	124	66	2	6	4	67
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Chipseals	ASP	-	-	-	-	14	467	334	72	30	1,620	1,292	80
	COM	-	-	-	-	1	3	2	67	7	401	274	68
	JCP	-	-	-	-	-	-	-	-	1	7	4	57
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Crack Sealing	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Microsurfacing	ASP	5	30	14	47	-	-	-	-	-	-	-	-
	COM	1	27	23	85	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Patching	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Full Depth PCC Patch	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	2	7	6	86
	JCP	1	51	34	67	3	32	7	22	4	55	19	35
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Whitetopping	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Replacement	ASP	1	2	2	100	4	153	30	20	4	55	14	25
	JCP	6	92	43	47	3	55	29	53	12	194	53	27

Table 2

Distribution of selected projects based on treatment and pavement type for each district with 3 BT and 3 AT data points (continued)

Treatment Types	Pavement Type	District 05				District 58				District 61			
		No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted
Overlay	**ASP**	38	1,453	1,061	73	39	1,633	1,150	70	50	1,423	1,103	78
	COM	11	195	104	53	6	371	289	78	6	335	89	27
	JCP	2	33	20	61	2	34	6	18	4	135	37	27
	CRC	1	15	5	33	-	-	-	-	-	-	-	-
Chipseals	**ASP**	37	1,873	1,358	73	28	1,041	796	76	23	1,106	944	85
	COM	2	143	46	32	10	406	241	59	2	46	25	54
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Crack Sealing	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Microsurfacing	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	1	47	41	87	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Patching	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	2	134	71	53	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Full Depth PCC Patch	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	2	33	19	58
	JCP	2	128	16	13	-	-	-	-	3	44	19	43
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Whitetopping	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	1	18	8	44	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Replacement	**ASP**	-	-	-	-	1	55	44	80	2	53	42	79
	JCP	2	57	52	-	-	-	-	-	3	61	12	20

Table 3

Distribution of selected projects based on treatment and pavement type for each district with 3 BT and 3 AT data points (continued)

Treatment Types	Pavement Type	District 62				District 07				District 08			
		No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted
Overlay	ASP	34	1,305	917	70	26	1,153	740	64	50	2,051	1,479	72
	COM	12	371	237	64	9	190	83	44	-	-	-	-
	JCP	3	161	148	92	7	159	55	35	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Chipseals	ASP	13	801	738	92	16	-	920	-	13	531	337	63
	COM	-	-	-	-	2	16	13	81	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	1	50	49	98
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Crack Sealing	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	4	60	40	67	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Microsurfacing	ASP	1	58	54	93	1	85	84	99	5	219	133	61
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Patching	ASP	1	44	23	52	-	-	-	-	3	88	64	73
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	1	21	16	76	-	-	-	-	3	112	91	81
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Full Depth PCC Patch	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	3	132	33	25	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Whitetopping	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Replacement	ASP	2	5	4	80	1	49	24	49	10	451	182	40
	JCP	2	11	7	64	2	32	6		7	119	71	60

Table 4
Distribution of selected projects based on treatment, pavement and distress types with 3 BT and 3 AT data points

Treatment Types	Pavement Type	International Roughness Index (IRI)				Rut				Alligator Cracking			
		No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted
Overlay	**ASP**	266	10,367	5,323	51	269	11,355	5,649	50	260	11,131	5,164	46
	COM	58	1,866	1,015	54	55	2,049	912	45	36	1,503	935	62
	JCP	18	327	160	49	-	-	-	-	6	182	61	34
	CRC	1	15	5	33	-	-	-	-	-	-	-	-
Chipseals	**ASP**	158	7,690	3,576	47	158	7,840	4,534	58	159	7,762	4,912	63
	COM	18	822	336	41	20	850	468	55	7	271	107	39
	JCP	2	57	39	68	-	-	-	-	1	50	49	98
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Crack Sealing	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	3	58	15	26	-	-	-	-	1	2	1	50
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Microsurfacing	**ASP**	7	344	172	50	7	288	177	61	9	336	229	68
	COM	2	74	24	32	2	47	41	87	2	74	13	18
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Patching	**ASP**	3	112	84	75	4	132	41	31	4	156	107	69
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	5	325	78	24	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
PCC Patch	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	3	38	15	39	4	40	23	58	-	-	-	-
	JCP	14	433	103	24	-	-	-	-	2	36	2	6
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Whitetopping	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	1	18	7	39	1	18	8	44	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Replacement	**ASP**	12	545	227	42	14	518	241	47	11	332	77	23
	JCP	23	474	148	31	-	-	-	-	11	158	74	47

Table 5
Distribution of selected projects based on treatment, pavement and distress types with 3 BT and 3 AT data points (continued)

Treatment Types	Pavement Type	Longitudinal Cracking				Transverse Cracking			
		No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted
Overlay	**ASP**	229	9,311	2,701	29	251	10,281	3,789	37
	COM	45	1,583	333	21	55	2,034	457	22
	JCP	24	672	69	10	24	707	262	37
	CRC	1	15	5	33	-	-	-	-
Chipseals	**ASP**	139	6,921	2,232	32	121	6,321	2,023	32
	COM	16	791	90	11	17	762	112	15
	JCP	2	57	12	21	2	57	7	12
	CRC	-	-	-	-	-	-	-	-
Crack Sealing	**ASP**	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-
	JCP	4	60	29	48	5	67	38	57
	CRC	-	-	-	-	-	-	-	-
Microsurfacing	**ASP**	8	209	34	16	8	223	31	14
	COM	1	47	1	2	2	74	7	9
	JCP	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-
Patching	**ASP**	1	44	18	41	1	44	23	52
	COM	-	-	-	-	-	-	-	-
	JCP	6	349	104	30	6	349	98	28
	CRC	-	-	-	-	-	-	-	-
PCC Patch	**ASP**	-	-	-	-	-	-	-	-
	COM	1	16	4	25	3	38	10	26
	JCP	14	435	78	18	14	435	75	17
	CRC	-	-	-	-	-	-	-	-
Whitetopping	**ASP**	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-
Replacement	**ASP**	18	686	142	21	20	755	152	20
	JCP	18	330	75	23	21	405	149	37

Table 6

Distribution of selected projects based on treatment and pavement types for all the districts with 1 BT and 3 AT data points

Treatment Types	Pavement Type	District 02				District 03				District 04			
		No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted
Overlay	ASP	32	1,3	1,318	98	45	2,0	1,987	99	42	1,7	1,746	99
	COM	21	809	786	97	20	315	311	99	17	498	497	100
	JCP	6	131	131	100	15	244	218	89	3	8	7	88
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Chipseals	ASP	-	-	-	-	14	467	334	72	30	1,6	1,292	80
	COM	2	9	8	89	1	3	3	100	7	401	399	100
	JCP	1	4	1	25	1	42	42	100	1	7	7	100
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Crack Sealing	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Microsurfacing	ASP	7	70	69	99	-	-	-	-	-	-	-	-
	COM	1	26	26	100	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Patching	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Full Depth PCC Patch	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Whitetopping	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Replacement	ASP	1	2	2	100	4	153	115	75	4	55	55	100
	JCP	7	99	87	88	3	55	51	93	18	349	225	64

Table 7
Distribution of selected projects based on treatment and pavement types for all the districts with 1 BT and 3 AT data points (continued)

Treatment Types	Pavement Type	District 05				District 58				District 61			
		No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted
Overlay	**ASP**	35	1,225	1,220	100	39	1,631	1,600	98	54	1,451	1,435	99
	COM	18	448	437	98	8	417	401	96	7	345	342	99
	JCP	3	35	35	100	2	34	34	100	6	140	137	98
	CRC	1	15	15	100	-	-	-	-	-	-	-	-
Chipseals	**ASP**	37	1,873	1,358	73	28	1,038	988	95	24	1,133	1,128	100
	COM	2	143	143	100	10	404	389	96	2	46	45	98
	JCP	1	8	8	100	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Crack Sealing	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Microsurfacing	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	1	47	47	100	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Patching	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	2	134	134	100	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
PCC Patch	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	2	33	33	100
	JCP	3	132	130	98	-	-	-	-	4	68	67	99
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Whitetopping	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	1	18	18	100	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Replacement	**ASP**	-	-	-	-	1	55	55	100	4	69	69	100
	JCP	3	60	60	100	-	-	-	-	3	61	61	100

Table 8

Distribution of selected projects based on treatment and pavement types for all the districts with 1 BT and 3 AT data points (continued)

Treatment Types	Pavement Type	District 62				District 07				District 08			
		No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted
Overlay	ASP	35	1,317	1,303	99	29	1,258	1,253	100	56	2,220	2,197	99
	COM	12	371	364	98	10	201	201	100	2	35	35	100
	JCP	4	307	307	100	8	163	162	99	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Chipseals	ASP	13	798	794	99	17	929	926	100	13	531	527	99
	COM	-	-	-	-	2	16	15	94	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	1	50	50	100
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Crack Sealing	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	1	9	9	100	-	-	-	-	-	-	-	-
	JCP	6	99	83	84	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Microsurfacing	ASP	1	58	58	100	1	85	85	100	5	219	215	98
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Patching	ASP	1	44	44	100	-	-	-	-	3	88	88	100
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	1	21	16	76	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
PCC Patch	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	3	132	131	99	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Whitetopping	ASP	-	-	-	-	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Replacement	ASP	3	7	7	100	2	52	52	100	10	451	450	100
	JCP	4	23	21	91	2	32	28	88	13	196	174	89

Table 9

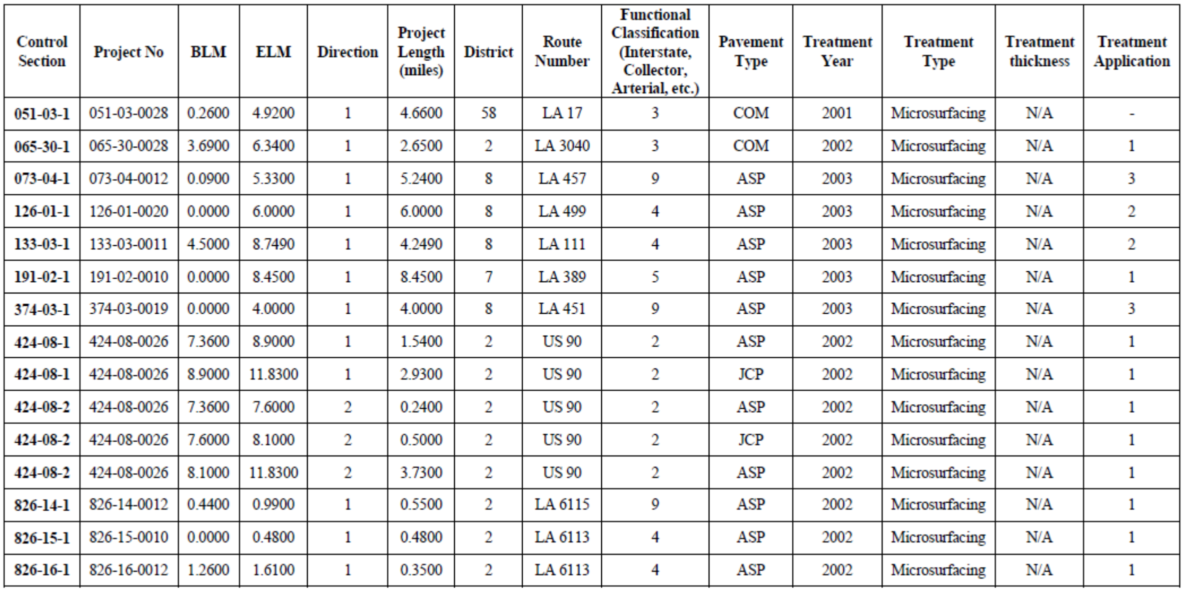
Distribution of selected projects based on treatment, pavement, and distress type with 1 BT and 3 AT data points

Treatment Types	Pavement Type	International Roughness Index (IRI)				Rut				Alligator Cracking			
		No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted
Overlay	**ASP**	351	13,693	10,875	79	363	14,039	13,584	97	310	12,489	8,453	68
	COM	104	3,246	2,675	82	112	3,413	3,145	92	43	1,882	1,092	58
	JCP	35	667	447	67	-	-	-	-	19	641	465	73
	CRC	1	15	9	60	1	15	15	100	-	-	-	-
Chipseals	**ASP**	171	8,156	6,066	74	176	8,383	8,202	98	167	8,003	5,644	71
	COM	23	956	626	65	26	1,022	982	96	7	270	130	48
	JCP	4	107	92	86	-	-	-	-	2	57	51	89
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Crack Sealing	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	1	9	5	56	1	9	6	67	-	-	-	-
	JCP	6	104	68	65	-	-	-	-	5	87	41	47
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Microsurfacing	**ASP**	13	431	314	73	14	432	327	76	13	431	306	71
	COM	2	73	25	34	2	73	66	90	2	73	16	22
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Patching	**ASP**	4	132	103	78	4	132	132	100	4	132	78	59
	COM	-	-	-	-	-	-	-	-	-	-	-	-
	JCP	3	155	79	51	-	-	-	-	1	21	21	100
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Full Depth PCC Patch	**ASP**	1	5	4	80	1	5	2	40	1	5	3	60
	COM	3	38	20	53	4	40	40	100	0	0	0	0
	JCP	16	461	254	55	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Whitetopping	**ASP**	-	-	-	-	-	-	-	-	-	-	-	-
	COM	1	18	7	39	-	18	18	100	-	-	-	-
	JCP	-	-	-	-	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-	-	-	-	-
Replacement	**ASP**	23	797	645	81	29	844	758	90	20	704	240	34
	JCP	45	818	437	53	-	-	-	-	24	368	234	64

Table 10
Distribution of selected projects based on treatment, pavement, and distress type with 1 BT and 3 AT data points (continued)

Treatment Types	Pavement Type	Longitudinal Cracking				Transverse Cracking			
		No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted	No. of Projects	Total 0.1 Log miles	Accepted 0.1 Log miles	% Accepted
Overlay	**ASP**	341	13,478	8,350	62	348	13,593	9,695	71
	COM	102	3,237	2,186	68	98	3,062	2,377	78
	JCP	42	1,033	703	68	43	1,045	724	69
	CRC	-	-	-	-	-	-	-	-
Chipseals	**ASP**	171	8,181	5,425	66	170	8,146	6,082	75
	COM	23	998	624	63	23	997	625	63
	JCP	3	99	95	96	3	99	95	96
	CRC	-	-	-	-	-	-	-	-
Crack Sealing	**ASP**	-	-	-	-	-	-	-	-
	COM	1	9	9	100	1	9	9	100
	JCP	6	104	56	54	6	104	68	65
	CRC	-	-	-	-	-	-	-	-
Microsurfacing	**ASP**	14	432	293	68	13	392	305	78
	COM	2	73	70	96	2	73	65	89
	JCP	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-
Patching	**ASP**	4	132	74	56	4	132	91	69
	COM	-	-	-	-	-	-	-	-
	JCP	3	155	57	37	3	155	79	51
	CRC	-	-	-	-	-	-	-	-
Full Depth PCC Patch	**ASP**	1	5	1	20	1	5	1	20
	COM	4	40	20	50	3	38	16	42
	JCP	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-
Whitetopping	**ASP**	-	-	-	-	-	-	-	-
	COM	-	-	-	-	-	18	1	6
	JCP	-	-	-	-	-	-	-	-
	CRC	-	-	-	-	-	-	-	-
Replacement	**ASP**	24	765	360	47	25	820	400	49
	JCP	42	699	245	35	36	549	294	54

Table 11
Example summary of candidate projects



Control Section	Project No	BLM	ELM	Direction	Project Length (miles)	District	Route Number	Functional Classification (Interstate, Collector, Arterial, etc.)	Pavement Type	Treatment Year	Treatment Type	Treatment thickness	Treatment Application
051-03-1	051-03-0028	0.2600	4.9200	1	4.6600	58	LA 17	3	COM	2001	Microsurfacing	N/A	-
065-30-1	065-30-0028	3.6900	6.3400	1	2.6500	2	LA 3040	3	COM	2002	Microsurfacing	N/A	1
073-04-1	073-04-0012	0.0900	5.3300	1	5.2400	8	LA 457	9	ASP	2003	Microsurfacing	N/A	3
126-01-1	126-01-0020	0.0000	6.0000	1	6.0000	8	LA 499	4	ASP	2003	Microsurfacing	N/A	2
133-03-1	133-03-0011	4.5000	8.7490	1	4.2490	8	LA 111	4	ASP	2003	Microsurfacing	N/A	2
191-02-1	191-02-0010	0.0000	8.4500	1	8.4500	7	LA 389	5	ASP	2003	Microsurfacing	N/A	1
374-03-1	374-03-0019	0.0000	4.0000	1	4.0000	8	LA 451	9	ASP	2003	Microsurfacing	N/A	3
424-08-1	424-08-0026	7.3600	8.9000	1	1.5400	2	US 90	2	ASP	2002	Microsurfacing	N/A	1
424-08-1	424-08-0026	8.9000	11.8300	1	2.9300	2	US 90	2	JCP	2002	Microsurfacing	N/A	1
424-08-2	424-08-0026	7.3600	7.6000	2	0.2400	2	US 90	2	ASP	2002	Microsurfacing	N/A	1
424-08-2	424-08-0026	7.6000	8.1000	2	0.5000	2	US 90	2	JCP	2002	Microsurfacing	N/A	1
424-08-2	424-08-0026	8.1000	11.8300	2	3.7300	2	US 90	2	ASP	2002	Microsurfacing	N/A	1
826-14-1	826-14-0012	0.4400	0.9900	1	0.5500	2	LA 6115	9	ASP	2002	Microsurfacing	N/A	1
826-15-1	826-15-0010	0.0000	0.4800	1	0.4800	2	LA 6113	4	ASP	2002	Microsurfacing	N/A	1
826-16-1	826-16-0012	1.2600	1.6100	1	0.3500	2	LA 6113	4	ASP	2002	Microsurfacing	N/A	1

Table 12
Example summary of candidate projects (continued)

Control Section	Project No	BLM	ELM	1_3_Project Acceptance	3_3_Project Acceptance	Total Project Cost ($)	Description of the Treatment
051-03-1	051-03-0028	0.2600	4.9200	Yes	Yes	216,796.0	M3_PLACE MICRO SURFACING-1 SCRATCH BOX APPL-1 FULL WIDTH APPL.,TEMP. SIGNS & BARR., PAVEMENT MRKS
065-30-1	065-30-0028	3.6900	6.3400	Yes	No	502,577.0	M3_APPLICATION OF A ONE COURSE NOVACHIP RESEAL, COLD PLANING AND RELATED WORK
073-04-1	073-04-0012	0.0900	5.3300	Yes	Yes	185,958.0	M3_THREE APPLICATION SURFACE TREATMENT
126-01-1	126-01-0020	0.0000	6.0000	Yes	Yes	135,393.0	M3TWO COURSE ASPHALTIC SURFACE TREATMENT
133-03-1	133-03-0011	4.5000	8.7490	Yes	Yes	81,378.0	M3TWO COURSE ASPHALTIC SURFACE TREATMENT
191-02-1	191-02-0010	0.0000	8.4500	Yes	Yes	77,135.7	M3-Micro Surfacing_1-COURSE CHIPSEAL _Chipseal _
374-03-1	374-03-0019	0.0000	4.0000	Yes	Yes	145,607.0	M3THREE COURSE ASPHALTIC SURFACE TREATMENT
424-08-1	424-08-0026	7.3600	8.9000	Yes	Yes	185,787.0	M3-Micro Surfacing_APPLICATION OF ONE COURSE NOVACHIP RESEAL AND APPROPRIATE PAVEMENT MARKINGS AND RELATED WORK._Novachip_
424-08-1	424-08-0026	8.9000	11.8300	Yes	Yes	353,478.0	M3-Micro Surfacing_APPLICATION OF ONE COURSE NOVACHIP RESEAL AND APPROPRIATE PAVEMENT MARKINGS ANDRELATED WORK._Novachip_
424-08-2	424-08-0026	7.3600	7.6000	Yes	No	29,470.0	M3APPLICATION OF ONE COURSE NOVACHIP RESEAL AND APPROPRIATE PAVEMENT MARKINGS AND RELATED WORK.
424-08-2	424-08-0026	7.6000	8.1000	Yes	No	61,396.0	M3APPLICATION OF ONE COURSE NOVACHIP RESEAL AND APPROPRIATE PAVEMENT MARKINGS AND RELATED WORK.
424-08-2	424-08-0026	8.1000	11.8300	Yes	No	458,014.0	M3APPLICATION OF ONE COURSE NOVACHIP RESEAL AND APPROPRIATE PAVEMENT MARKINGS AND RELATED WORK.
826-14-1	826-14-0012	0.4400	0.9900	Yes	Yes	47,751.0	M3-Micro Surfacing_APPLICATION OF ONE COURSE NOVACHIP W/ APPROPRIATE MARKINGS AND RELATED WORK._Novachip_
826-15-1	826-15-0010	0.0000	0.4800	Yes	Yes	53,818.0	M3-Micro Surfacing_APPLICATION OF ONE COURSE NOVACHIP W/ APPROPRIATE PAVEMENT MARKINGS AND RELATED WORK_Novachip_
826-16-1	826-16-0012	1.2600	1.6100	Yes	Yes	43,841.0	M3-Micro Surfacing_APPLICATION OF ONE COURSE OF NOVACHIP TO RESEAL RDWY. AND RELATED WORK_Novachip_
826-51-1	826-51-0002	0.0000	0.0500	Yes	Yes	11,883.0	M3-Micro Surfacing_AGG. SURFACE TREATMENT, REFLECTORIZED RAISED PAVE. MARKERS PLASTIC PAVE. STRIPING & NOVACHIP__
835-06-1	835-06-0016	4.0300	6.3300	Yes	Yes	71,764.0	M3TWO COURSE ASPHALTIC SURFACE TREATMENT
846-11-1	846-11-0005	0.0000	5.7300	Yes	Yes	71,663.0	M30

APPENDIX D

Flexible Pavement with Chipseal Treatment

IRI

Table 1

IRI statistics for flexible pavement

Regression Statistics				
Multiple R				0.93
R Square				0.86
Adjusted R Square				0.86
Standard Error				0.12
Observations				519
F-statistics				1073.93
Significance-F				3.97E-221
Coefficients	Value	Standard Error	t-stats	p-values
a_o	1.045	0.07644	13.67	1.57E-36
a_1	0.8015	0.01453	55.17	2.53E-218
a_2	-0.1937	0.09173	-2.11	3.52E-02
a_3	0.002740	0.0002336	11.73	2.52E-28

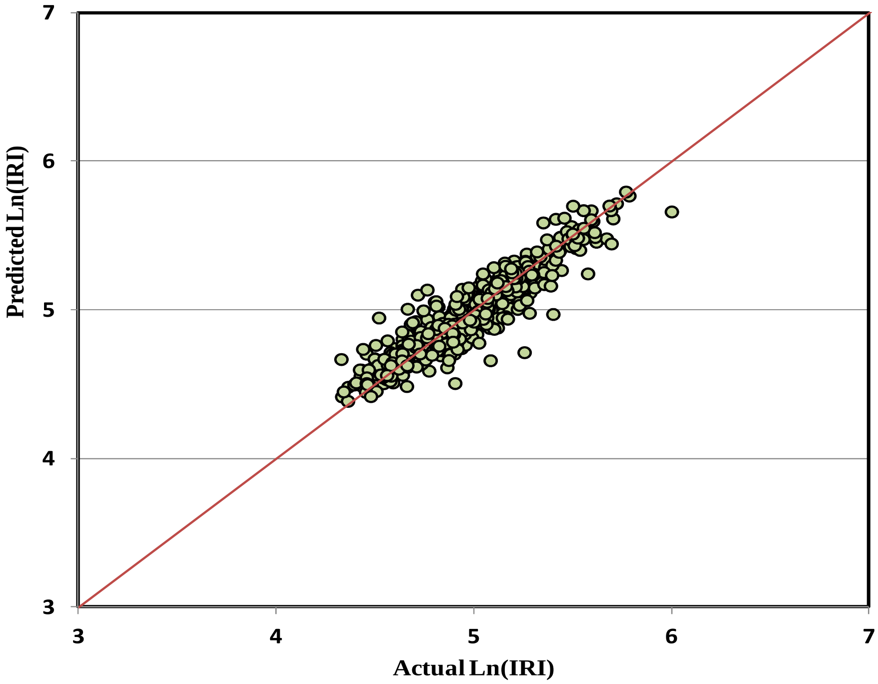


Figure 1

Actual vs predicted ln(IRI) for flexible pavement.

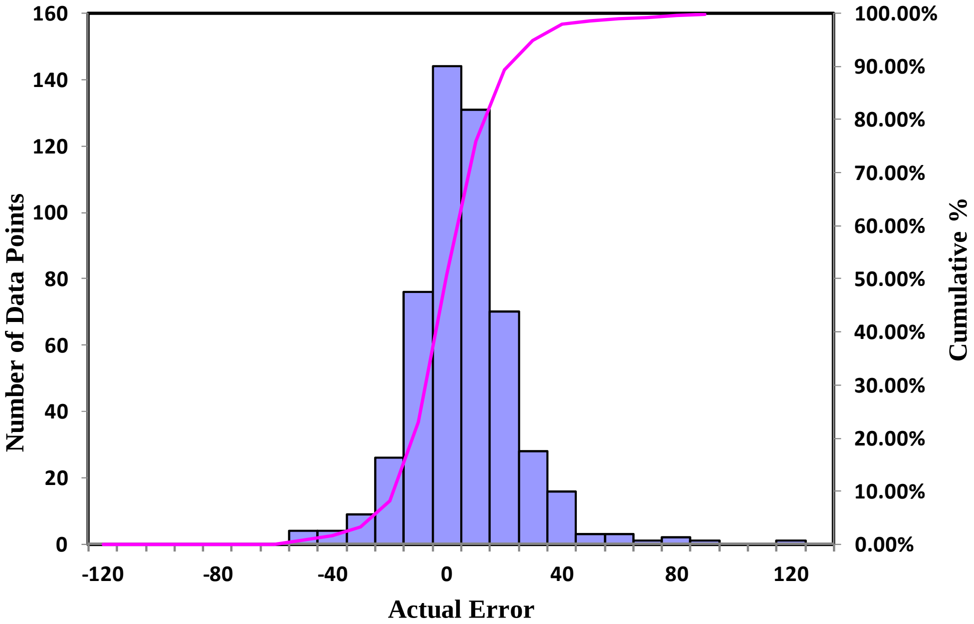


Figure 2

Error distribution of actual IRI for flexible pavement

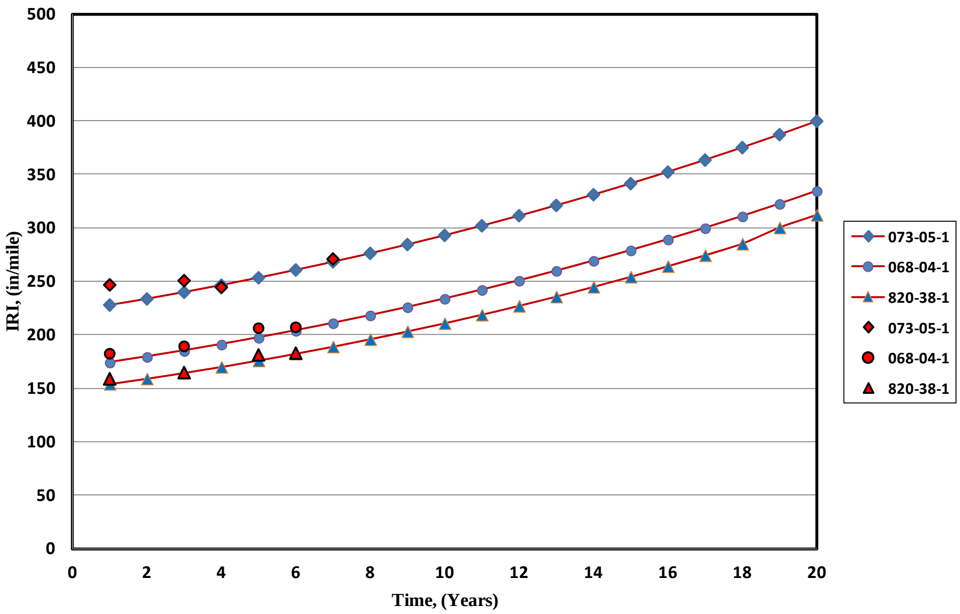


Figure 3

Behavior of IRI for flexible pavement

Rut

Table 2

Rut statistics for flexible pavement

Regression Statistics				
Multiple R			0.54	
R Square			0.29	
Adjusted R Square			0.29	
Standard Error			0.30	
Observations			439	
F-statistics			59.45	
Significance-F			3.15E-32	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-0.9981	0.08549	-11.68	1.38E-27
a_1	0.007529	0.002832	2.66	8.13E-03
a_2	0.4620	0.03721	12.41	1.68E-30
a_3	0.06328	0.03231	1.96	5.09E-02

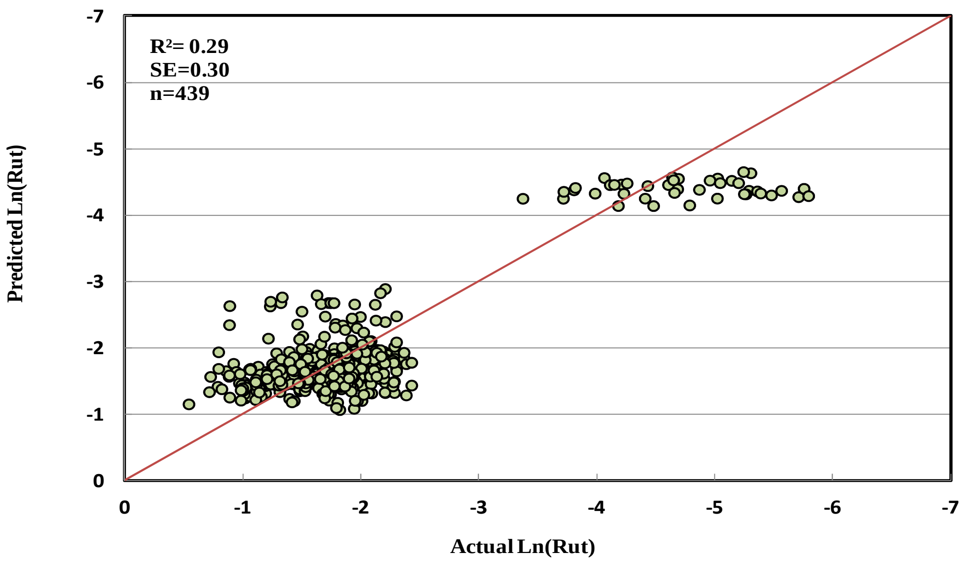


Figure 4

Predicted vs actual ln(Rut) for flexible pavement.

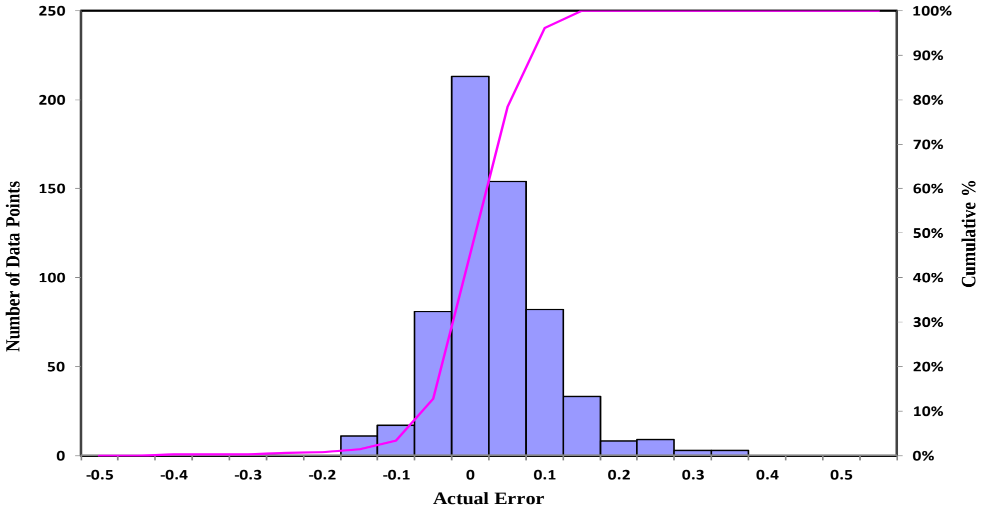


Figure 5

Error distribution of actual rut for flexible pavement

Transverse Crack

Table 3

Statistics of the regression analysis of TC model for flexible pavement

<table>
<tr><td colspan="5">Regression Statistics</td></tr>
<tr><td colspan="3">Multiple R</td><td colspan="2">0.59</td></tr>
<tr><td colspan="3">R Square</td><td colspan="2">0.35</td></tr>
<tr><td colspan="3">Adjusted R Square</td><td colspan="2">0.34</td></tr>
<tr><td colspan="3">Standard Error</td><td colspan="2">1.67</td></tr>
<tr><td colspan="3">Observations</td><td colspan="2">531</td></tr>
<tr><td colspan="3">F-statistics</td><td colspan="2">70.57</td></tr>
<tr><td colspan="3">Significance-F</td><td colspan="2">7.90E-48</td></tr>
<tr><td>Coefficients</td><td>Value</td><td>Standard Error</td><td>t-stats</td><td>p-values</td></tr>
<tr><td>a_o</td><td>-8.836</td><td>0.6441</td><td>-13.72</td><td>7.93E-37</td></tr>
<tr><td>a_1</td><td>0.1390</td><td>0.04533</td><td>3.07</td><td>2.28E-03</td></tr>
<tr><td>a_2</td><td>0.0002208</td><td>0.00002192</td><td>10.07</td><td>6.10E-22</td></tr>
<tr><td>a_3</td><td>0.5514</td><td>0.06766</td><td>8.15</td><td>2.69E-15</td></tr>
<tr><td>a_4</td><td>-3.709</td><td>0.7168</td><td>-5.17</td><td>3.26E-07</td></tr>
</table>

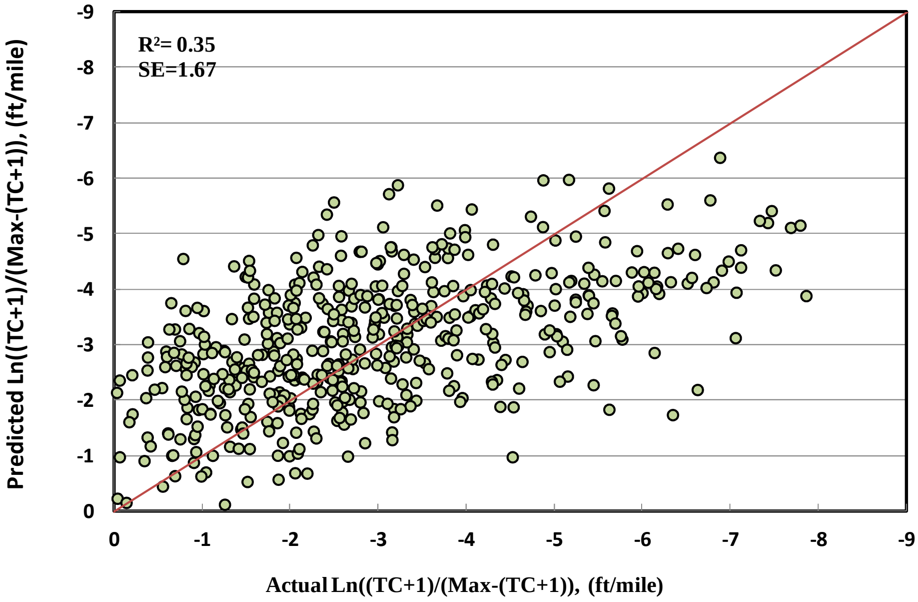


Figure 6

Predicted versus actual Ln((TC+1)/(Max-(TC+1))

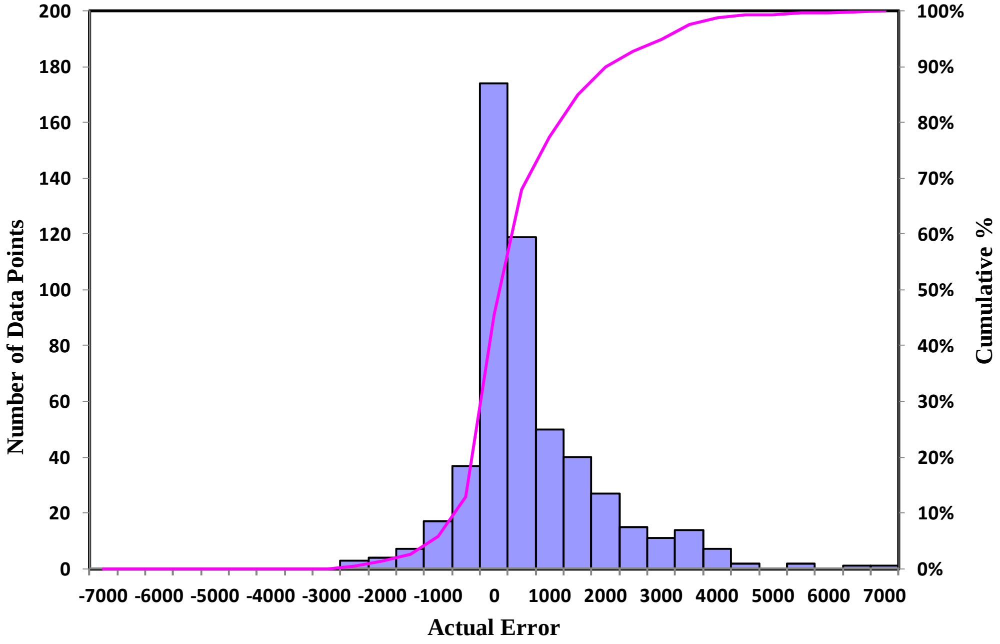


Figure 7

Actual error distribution of TC using regression model

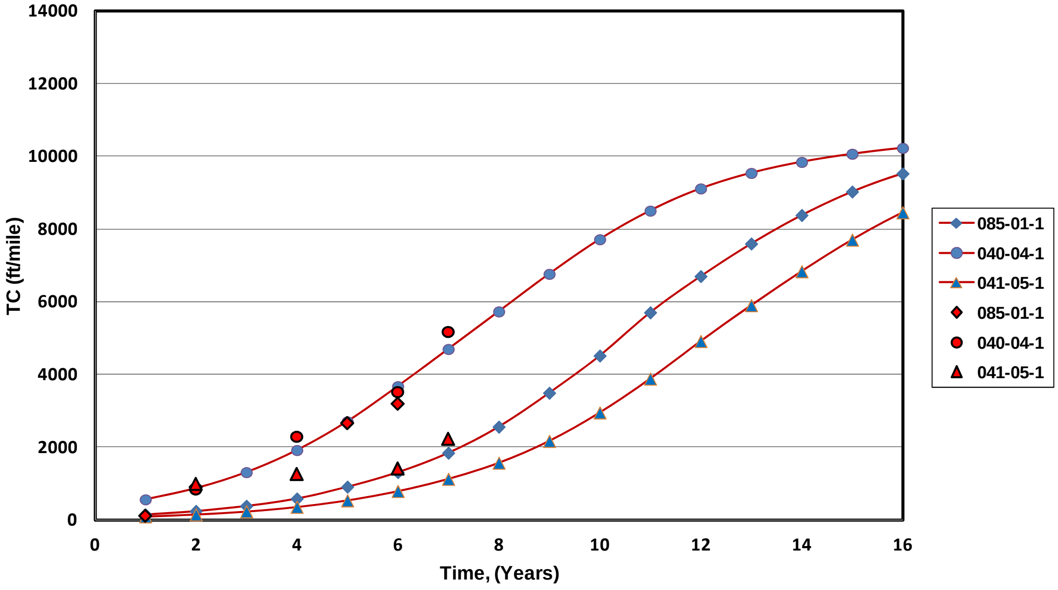


Figure 8

TC model behavior for flexible pavement

Longitudinal Cracking

Table 4

Statistics of the regression analysis of LC model for flexible pavement

Regression Statistics				
Multiple R				0.58
R Square				0.33
Adjusted R Square				0.33
Standard Error				1.55
Observations				530
F-statistics				86.96
Significance-F				1.05E-45
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-8.372	0.4262	-19.64	7.67E-65
a_1	0.2543	0.08903	2.86	4.46E-03
a_2	0.3468	0.05691	6.09	2.13E-09
a_3	0.0002568	0.00001835	14.00	4.64E-38

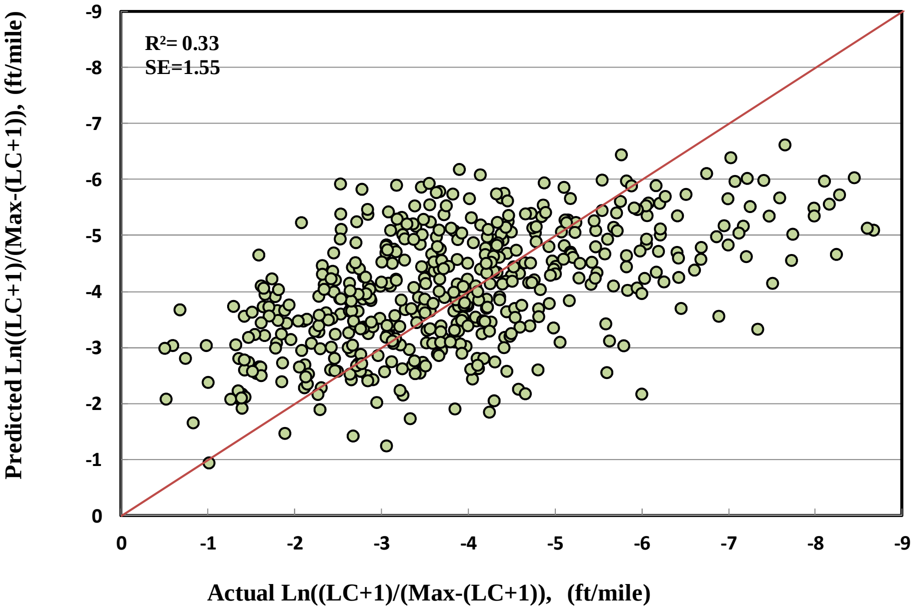


Figure 9

Predicted versus actual Ln((LC+1)/(Max-(LC+1))for flexible pavement

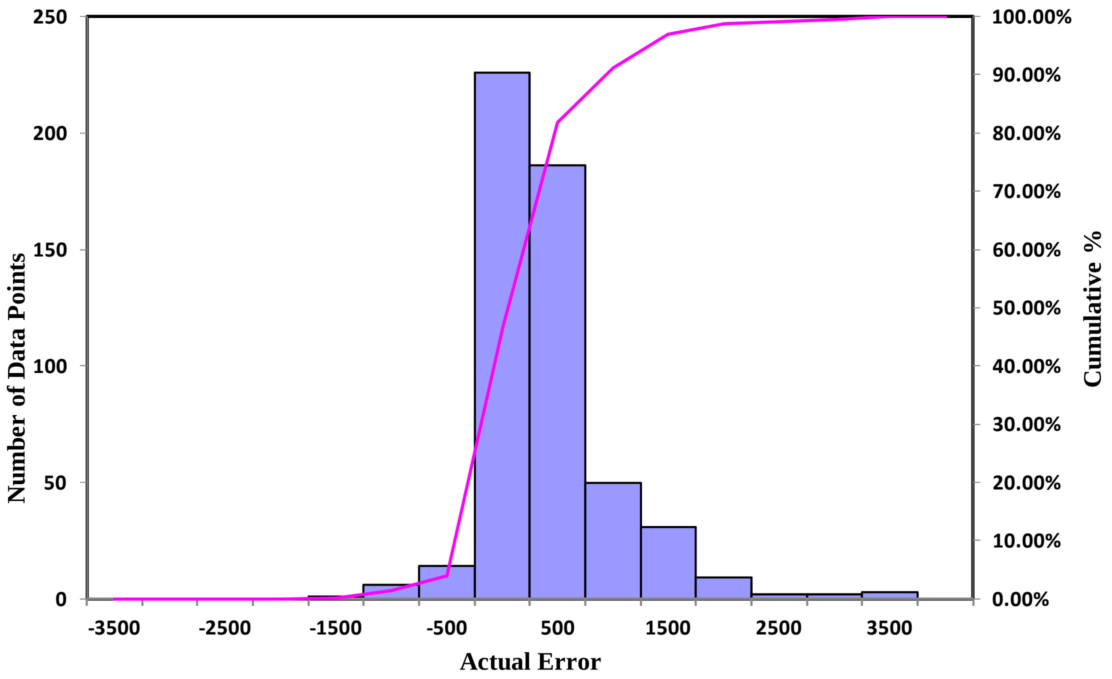


Figure 10

Actual error distribution of longitudinal crack using regression model

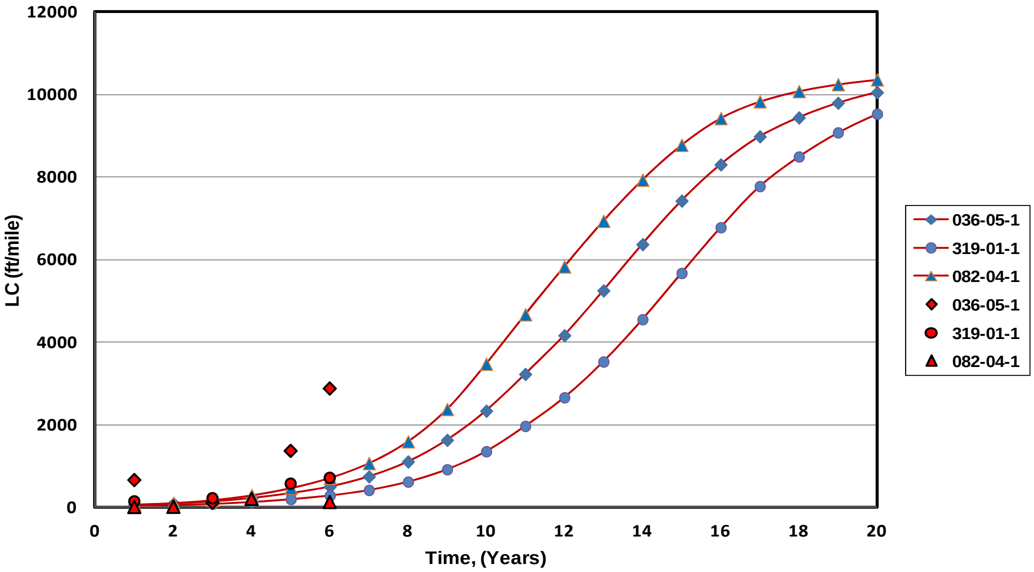


Figure 11

LC model behavior for flexible pavement

Fatigue Cracking

Table 5

Statistics of the regression analysis of FC model for flexible pavement

Regression Statistics				
Multiple R				0.45
R Square				0.20
Adjusted R Square				0.20
Standard Error				2.10
Observations				456
F-statistics				57.42
Significance-F				5.96E-23
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-6.295	0.2740	-22.97	5.51E-78
a_1	0.3750	0.1274	2.94	3.40E-03
a_2	0.0002643	0.00002720	9.71	2.17E-20

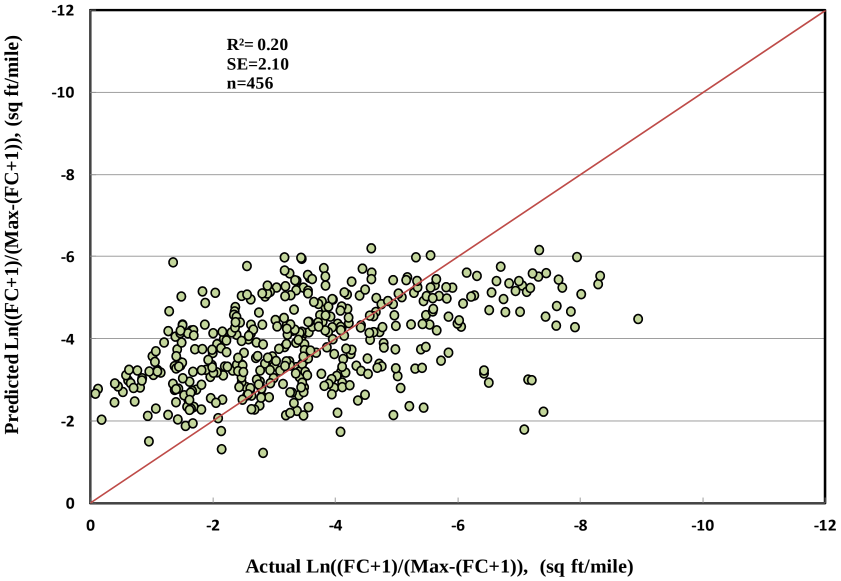


Figure 12

Predicted versus actual Ln((FC+1)/(Max-(FC+1))for flexible pavement

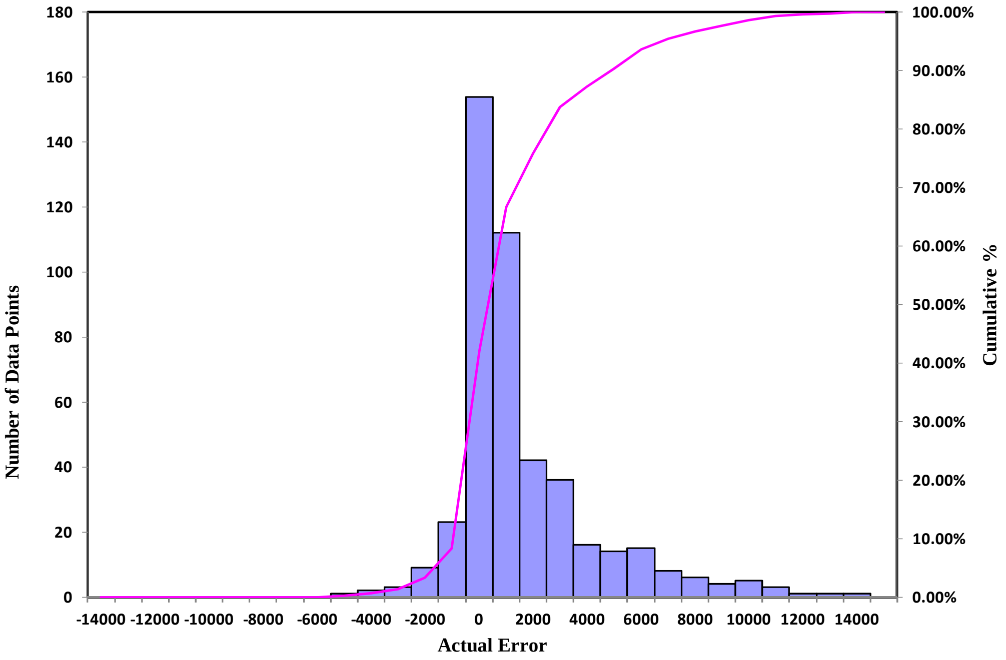


Figure 13

Actual error distribution of rut using regression model

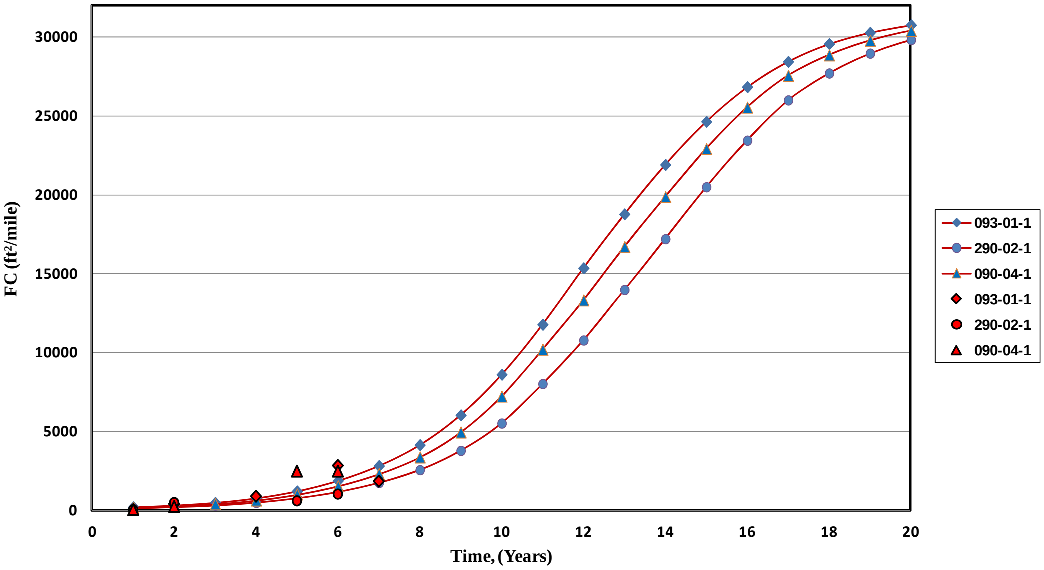


Figure 14
LC model behavior for flexible pavement

Flexible Pavement Microsurfacing Treatment

IRI

Table 6
Statistics of the regression analysis of IRI model for flexible pavement

Regression Statistics				
Multiple R				0.94
R Square				0.88
Adjusted R Square				0.87
Standard Error				0.17
Observations				26
F-statistics				55.35
Significance-F				2.06E-10
Coefficients	Value	Standard Error	t-stats	p-values
a_o	1.2518	0.6232	2.01	5.70E-02
a_1	0.001121	0.0003895	2.88	8.71E-03
a_2	0.6281	0.1483	4.24	3.38E-04
a_3	0.2062	0.06645	3.10	5.18E-03

Rut

Table 7
Statistics of the regression analysis of Rut model for flexible pavement

Regression Statistics				
Multiple R			0.74	
R Square			0.55	
Adjusted R Square			0.49	
Standard Error			0.25	
Observations			28	
F-statistics			9.65	
Significance-F			2.31E-04	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-1.7954	0.1298	-13.84	6.21E-13
a_1	0.320533	0.08785	3.65	1.27E-03
a_2	0.01257	0.004285	2.93	7.27E-03
a_3	0.03273	0.02470	1.33	1.98E-01

Transverse Crack

Table 8

Statistics of the regression analysis of TC model for flexible pavement

<table>
<tr><th colspan="5">Regression Statistics</th></tr>
<tr><td colspan="3">Multiple R</td><td colspan="2">0.74</td></tr>
<tr><td colspan="3">R Square</td><td colspan="2">0.55</td></tr>
<tr><td colspan="3">Adjusted R Square</td><td colspan="2">0.51</td></tr>
<tr><td colspan="3">Standard Error</td><td colspan="2">2.04</td></tr>
<tr><td colspan="3">Observations</td><td colspan="2">34</td></tr>
<tr><td colspan="3">F-statistics</td><td colspan="2">12.38</td></tr>
<tr><td colspan="3">Significance-F</td><td colspan="2">1.92E-05</td></tr>
<tr><td>Coefficients</td><td>Value</td><td>Standard Error</td><td>t-stats</td><td>p-values</td></tr>
<tr><td>a_o</td><td>-10.86</td><td>1.213</td><td>-8.95</td><td>5.62E-10</td></tr>
<tr><td>a_1</td><td>0.04584</td><td>0.01862</td><td>2.46</td><td>1.98E-02</td></tr>
<tr><td>a_2</td><td>0.7637</td><td>0.1702</td><td>4.49</td><td>9.86E-05</td></tr>
<tr><td>a_3</td><td>3.03107</td><td>2.855</td><td>1.06</td><td>2.97E-01</td></tr>
</table>

Longitudinal Crack

Table 9

Statistics of the regression analysis of LC model for flexible pavement

Regression Statistics				
Multiple R		0.77		
R Square		0.59		
Adjusted R Square		0.55		
Standard Error		1.77		
Observations		34		
F-statistics		14.62		
Significance-F		4.77E-06		
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-12.387	1.410	-8.79	8.47E-10
a_1	0.5171	0.2460	2.10	4.40E-02
a_2	2.49E-04	9.53E-05	2.61	1.39E-02
a_3	0.9810	1.76E-01	5.58	4.49E-06

Fatigue Crack

Table 10

Statistics of the regression analysis of FC model for flexible pavement

Regression Statistics				
Multiple R				0.74
R Square				0.55
Adjusted R Square				0.51
Standard Error				1.92
Observations				24
F-statistics				12.81
Significance-F				2.31E-04
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-8.839	1.063	-8.31	4.43E-08
a_1	1.384	0.5282	2.62	1.60E-02
a_2	0.03989	0.008131	4.91	7.49E-05

Flexible Pavement Replacement (New Pavement)

IRI

Table 11

Statistics of the regression analysis of IRI model for flexible pavement

Regression Statistics				
Multiple R			0.78	
R Square			0.60	
Adjusted R Square			0.58	
Standard Error			0.18	
Observations			57	
F-statistics			26.99	
Significance-F			9.85E-11	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	4.906	0.0835	58.76	6.25E-50
a_1	0.01145	0.002878	3.98	2.13E-04
a_2	-0.02843	0.005162	-5.51	1.09E-06
a_3	-0.8824	0.1125	-7.84	2.00E-10

Rut

Table 12

Statistics of the regression analysis of Rut model for flexible pavement

Regression Statistics				
Multiple R			0.90	
R Square			0.81	
Adjusted R Square			0.80	
Standard Error			0.66	
Observations			65	
F-statistics			84.45	
Significance-F			1.09E-21	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-2.565	0.2593	-9.89	2.67E-14

a_1	0.06399	0.00412	15.53	7.33E-23
a_2	-0.07904	0.0427	-1.85	6.91E-02

Transverse Crack

Table 13

Statistics of the regression analysis of TC model for flexible pavement

Regression Statistics				
Multiple R			0.73	
R Square			0.53	
Adjusted R Square			0.51	
Standard Error			2.14	
Observations			57	
F-statistics			30.05	
Significance-F			1.69E-09	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-10.04	0.9725	-10.33	2.17E-14
a_1	1.836E-05	2.62E-06	7.01	4.01E-09
a_2	2.665	0.5425	4.91	8.70E-06

Longitudinal Crack

Table 14

Statistics of the regression analysis of LC model for flexible pavement

Regression Statistics				
Multiple R			0.63	
R Square			0.40	
Adjusted R Square			0.38	
Standard Error			2.10	
Observations			50	
F-statistics			15.77	
Significance-F			5.76E-06	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-9.347	1.0540	-8.87	1.33E-11
a_1	1.419E-05	2.75E-06	5.15	4.98E-06
a_2	2.0370	0.5500	3.70	5.58E-04

Fatigue Crack

Table 15

Statistics of the regression analysis of FC model for flexible pavement

Regression Statistics				
Multiple R			0.87	
R Square			0.76	
Adjusted R Square			0.73	
Standard Error			2.00	
Observations			48	
F-statistics			26.86	
Significance-F			4.42E-12	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-4.250	2.0551	-2.07	4.48E-02
a_1	0.9430	3.04E-01	3.10	3.44E-03
a_2	3.172E-05	9.74E-06	3.26	2.24E-03
a_3	-0.3644	0.17455	-2.09	4.29E-02
a_4	-0.3447	0.0712	-4.84	1.78E-05
a_5	-24.17	5.53150	-4.37	7.99E-05

Composite Pavement and Chipseal Treatment

International Roughness Index (IRI) Model

Table 16

Statistics of the regression analysis of IRI model for composite pavement

Regression Statistics				
Multiple R			0.66	
R Square			0.43	
Adjusted R Square			0.40	
Standard Error			0.17	
Observations			54	
F-statistics			12.59	
Significance-F			$2.98x10^{-6}$	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	2.3312	0.630	3.702	0.001
a_1	0.0621	0.012	5.177	0.000
a_2	0.4059	0.116	3.501	0.001
a_3	1.71x10-06	0.000	1.877	0.066

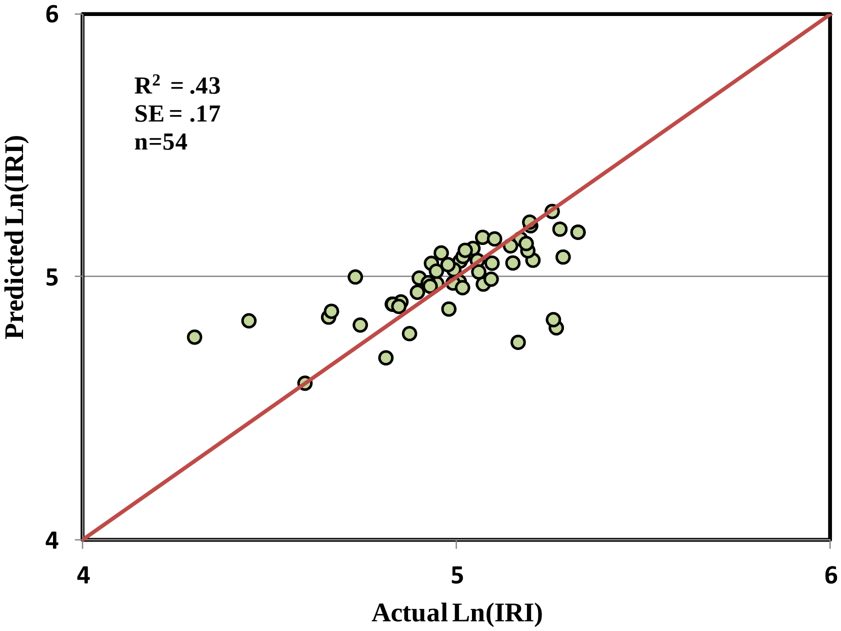


Figure 15

Predicted versus actual ln(IRI) for composite pavement

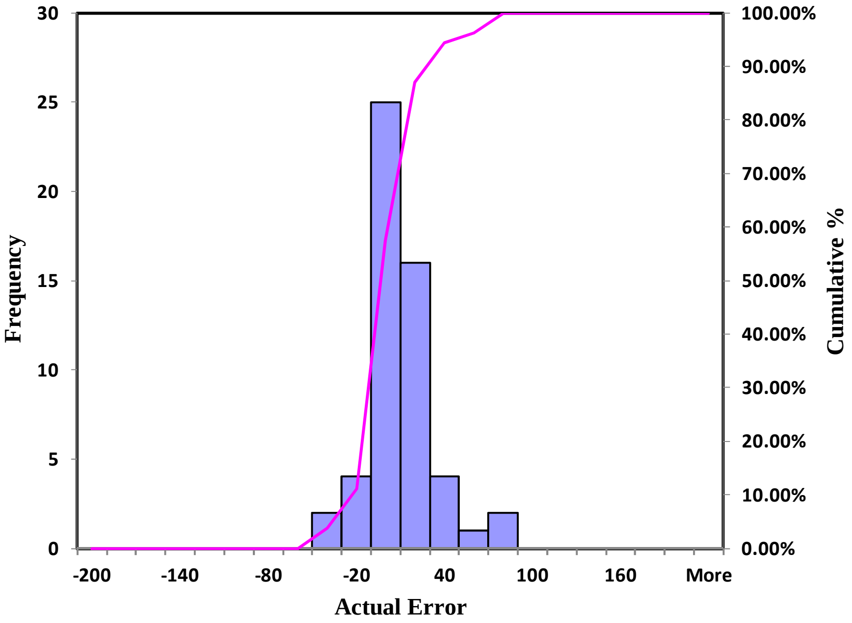


Figure 16

Actual error distribution of IRI for composite pavement

Rut

Table 17

Statistics of the regression analysis of Rut model for composite pavement

Regression Statistics				
Multiple R			0.88	
R Square			0.77	
Adjusted R Square			0.76	
Standard Error			0.67	
Observations			71	
F-statistics			113.64	
Significance-F			$2.07x10^{-22}$	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-5.603	0.575	-9.736	0.000
a_1	0.335	0.061	5.498	0.000
a_2	0.073	0.016	4.704	0.000

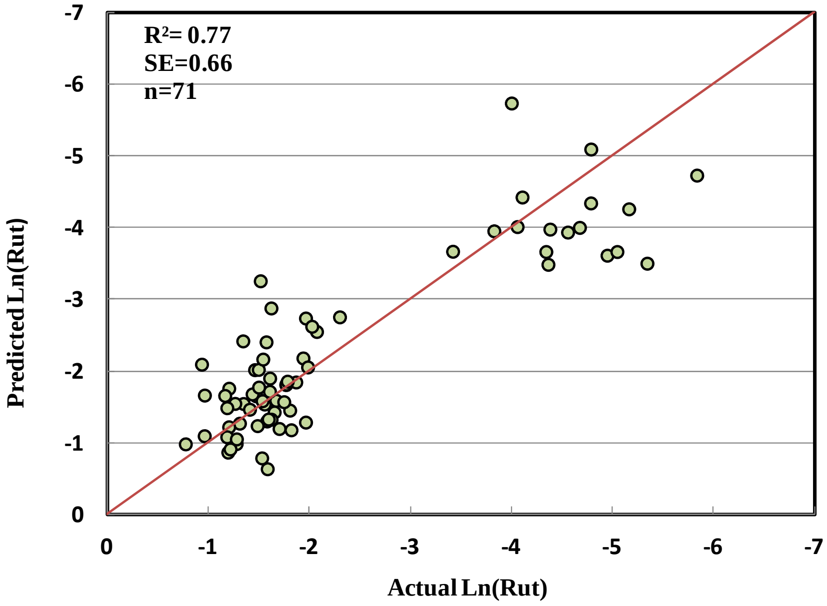


Figure 17

Predicted versus actual Ln(Rut) for composite pavement

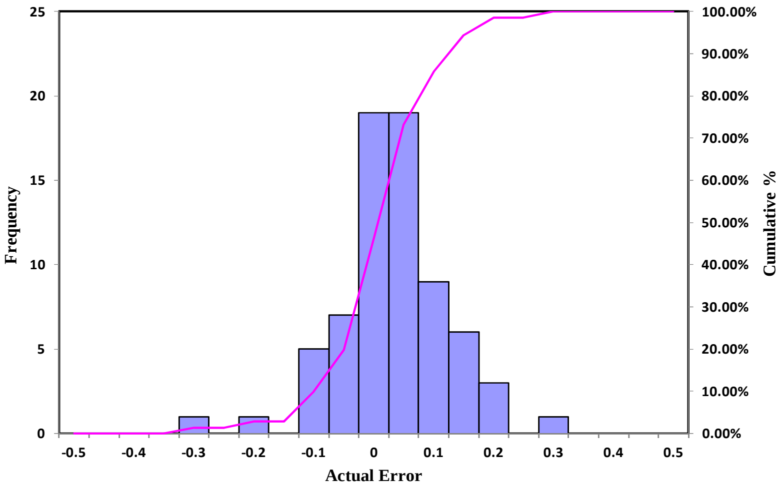


Figure 18

Actual error distribution of rut using regression model

Transverse Cracking

Table 18

Statistics of the regression analysis of TC model for composite pavement

<table>
<tr><td colspan="5">Regression Statistics</td></tr>
<tr><td colspan="3">Multiple R</td><td colspan="2">0.58</td></tr>
<tr><td colspan="3">R Square</td><td colspan="2">0.33</td></tr>
<tr><td colspan="3">Adjusted R Square</td><td colspan="2">0.30</td></tr>
<tr><td colspan="3">Standard Error</td><td colspan="2">2.22</td></tr>
<tr><td colspan="3">Observations</td><td colspan="2">58</td></tr>
<tr><td colspan="3">F-statistics</td><td colspan="2">9.06</td></tr>
<tr><td colspan="3">Significance-F</td><td colspan="2">5.89E-05</td></tr>
<tr><td>Coefficients</td><td>Value</td><td>Standard Error</td><td>t-stats</td><td>p-values</td></tr>
<tr><td>a_o</td><td>-6.4665</td><td>2.00462</td><td>-3.22581</td><td>0.00214</td></tr>
<tr><td>a_1</td><td>0.4465</td><td>0.22494</td><td>1.98480</td><td>0.05226</td></tr>
<tr><td>a_2</td><td>-5.9361</td><td>1.88553</td><td>-3.14822</td><td>0.00267</td></tr>
<tr><td>a_3</td><td>2.497E-04</td><td>0.00010</td><td>2.56815</td><td>0.01302</td></tr>
</table>

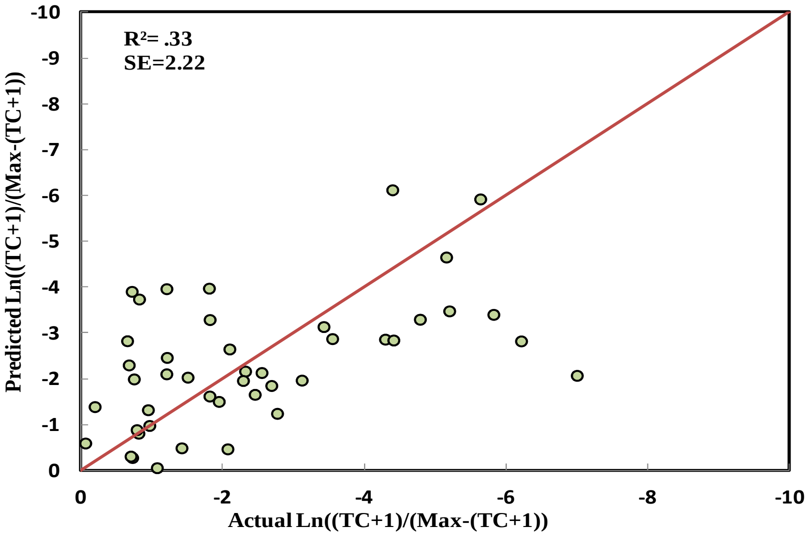


Figure 19

Predicted versus actual Ln((TC+1)/(Max-(TC+1))for composite pavement

Longitudinal Cracking

Table 19

Statistics of the regression analysis of LC model for composite pavement

Regression Statistics				
Multiple R			0.67	
R Square			0.44	
Adjusted R Square			0.42	
Standard Error			2.26	
Observations			53	
F-statistics			19.843	
Significance-F			4.52973E-07	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-7.661314	0.9018605	-8.49501	2.881E-11
a_1	0.0437193	0.018033	2.4243981	0.018991
a_2	4.850E-04	9.478E-05	5.1166523	4.962E-06

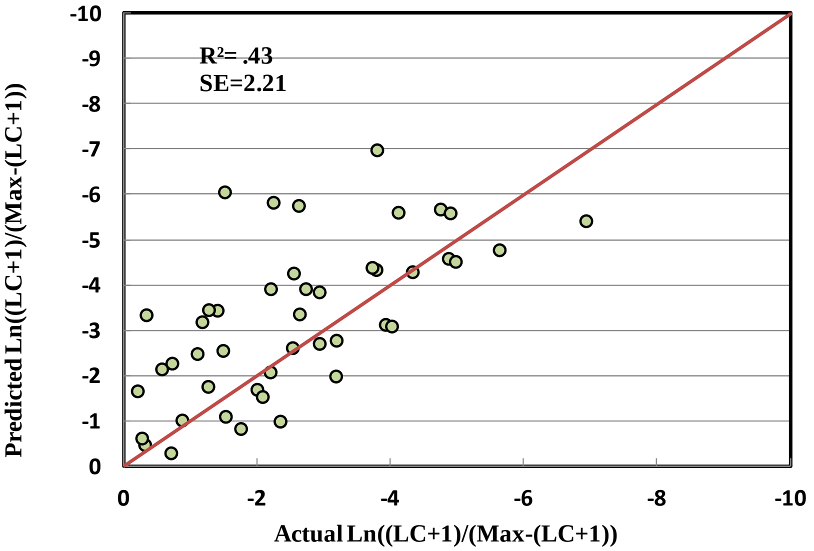


Figure 20

Predicted versus actual Ln((LC+1)/(Max-(LC+1))for composite pavement

Fatigue Cracking

Table 20

Statistics of the regression analysis of FC model for composite pavement

Regression Statistics				
Multiple R			0.87	
R Square			0.75	
Adjusted R Square			0.71	
Standard Error			1.66	
Observations			9.00	
F-statistics			20.86	
Significance-F			2.58E-03	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-10.777	1.803	-5.978	0.001
a_1	0.189	0.041	4.568	0.003

Composite Pavement and Microsurfacing Treatment

International Roughness Index

Table 21

Statistics of the regression analysis of IRI model for composite pavement

Regression Statistics				
Multiple R				0.98
R Square				0.96
Adjusted R Square				0.95
Standard Error				0.0204
Observations				4
F-statistics				61.617
Significance-F				0.0158
Coefficients	Value	Standard Error	t-stats	p-values
a_o	4.24021	0.02138	198.318	2.5E-05
a_1	0.00311	0.0004	7.84968	0.01584

Rut

Table 22

Statistics of the regression analysis of Rut model for composite pavement

Regression Statistics				
Multiple R				0.99
R Square				0.99
Adjusted R Square				0.66
Standard Error				0.05
Observations				5
F-statistics				4264.251
Significance-F				0.000234
Coefficients	Value	Standard Error	t-stats	p-values
a_o	0.0000			
a_1	0.4195	0.03998	10.4915	0.00185
a_2	1.3390	0.03201	41.836	3E-05

Transverse Cracking

Table 23

Statistics of the regression analysis of TC model for composite pavement

Regression Statistics				
Multiple R			0.94	
R Square			0.89	
Adjusted R Square			0.87	
Standard Error			0.71	
Observations			363	
F-statistics			39.73	
Significance-F			1.48E-03	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-6.4119	1.1187	-9.2015	0
a_1	0.0712	0.0985	3.5701	0.0004

Longitudinal Cracking

Table 24

Statistics of the regression analysis of LC model for composite pavement

Regression Statistics				
Multiple R			0.85	
R Square			0.73	
Adjusted R Square			0.69	
Standard Error			1.63	
Observations			8.00	
F-statistics			16.250	
Significance-F			6.87E-03	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-8.228776	1.3116572	-6.273572	0.0007624
a_1	0.0931332	0.0231032	4.0311824	0.0068711

Fatigue Cracking

Table 25

Statistics of the regression analysis of FC model for composite pavement

Regression Statistics				
Multiple R			1	
R Square			1	
Adjusted R Square			65535	
Standard Error			0	
Observations			2	
F-statistics			-	
Significance-F			-	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-8.4069			
a_1	0.0923			

JCP Pavement Chipseal Treatment

IRI

Table 26

Statistics of the regression analysis of IRI model for JCP pavement

Regression Statistics				
Multiple R				0.99
R Square				0.99
Adjusted R Square				0.99
Standard Error				0.05
Observations				11
F-statistics				227.59
Significance-F				2.44E-07
Coefficients	Value	Standard Error	t-stats	p-values
a_o	0.5278	0.17916	2.94588	0.02153
a_1	0.8452	0.03918	21.5729	1.2E-07
a_2	6.105E-03	0.00109	5.61097	0.00081
a_3	0.0333	0.00771	4.32451	0.00346

Rut

Table 27

Statistics of the regression analysis of Rut model for JCP pavement

Regression Statistics				
Multiple R				0.9998
R Square				0.9996
Adjusted R Square				0.9992
Standard Error				0.0059
Observations				3
F-statistics				2538.783131
Significance-F				0.0126
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-1.9575	0.00564	-346.77	0.00184
a_1	0.23439	0.00465	50.3863	0.01263

Transverse Crack

Table 28

Statistics of the regression analysis of TC model for JCP pavement

Regression Statistics				
Multiple R			0.712	
R Square			0.507	
Adjusted R Square			0.452	
Standard Error			1.495	
Observations			11	
F-statistics			9.25	
Significance-F			1.40E-02	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-4.2131	0.8745	-4.8179	0.0009
a_1	0.0554	0.0182	3.0415	0.0140

Longitudinal Cracking

Table 29

Statistics of the regression analysis of LC model for JCP pavement

Regression Statistics				
Multiple R			0.77	
R Square			0.60	
Adjusted R Square			0.51	
Standard Error			1.51	
Observations			12	
F-statistics			6.703	
Significance-F			0.016	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-11.1630	2.5625	-4.3562	0.0018
a_1	0.5490	0.2447	2.2437	0.0515
a_2	0.4768	0.2454	1.9432	0.0839

Fatigue Cracking

Table 30

Statistics of the regression analysis of FC model for JCP pavement

Regression Statistics				
Multiple R			0.95	
R Square			0.91	
Adjusted R Square			0.87	
Standard Error			1.11	
Observations			4	
F-statistics			20.24	
Significance-F			4.60E-02	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-8.006	1.140	-7.024	0.020
a_1	0.145	0.032	4.499	0.046

JCP Pavement Microsurfacing Treatment

IRI

Table 31

Statistics of the regression analysis of IRI model for JCP pavement

Regression Statistics				
Multiple R				0.89
R Square				0.80
Adjusted R Square				0.76
Standard Error				0.09
Observations				7.00
F-statistics				20.12
Significance-F				6.48E-03
Coefficients	Value	Standard Error	t-stats	p-values
a_o	3.99548	0.06858	58.2592	2.8E-08
a_1	0.00547	0.00122	4.48587	0.00648

Rut

Table 32

Statistics of the regression analysis of Rut model for JCP pavement

Regression Statistics				
Multiple R				0.77
R Square				0.59
Adjusted R Square				0.51
Standard Error				0.12
Observations				3
F-statistics				7.334
Significance-F				0.042
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-2.0818	0.07924	-26.273	1.5E-06
a_1	0.18451	0.06813	2.70807	0.04237

Transverse Cracking

Table 33

Statistics of the regression analysis of TC model for JCP pavement

Regression Statistics				
Multiple R				0.98
R Square				0.95
Adjusted R Square				0.95
Standard Error				0.33
Observations				7
F-statistics				102.25
Significance-F				1.52E-04
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-5.2807	0.2495	-21.1613	0.0000
a_1	0.0455	4.44E-03	10.2465	0.0002

Longitudinal Cracking

Table 34

Statistics of the regression analysis of LC model for JCP pavement

Regression Statistics				
Multiple R				0.83
R Square				0.68
Adjusted R Square				0.63
Standard Error				1.57
Observations				8
F-statistics				12.942
Significance-F				0.011
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-10.7173	1.1579	-9.2562	0.0001
a_1	0.0765	0.0213	3.5974	0.0114

Fatigue Cracking

Table 35

Statistics of the regression analysis of FC model for JCP pavement

Regression Statistics				
Multiple R			0.96	
R Square			0.92	
Adjusted R Square			0.84	
Standard Error			1.57	
Observations			3.00	
F-statistics			11.16	
Significance-F			1.85E-01	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-11.078	1.790	-6.188	0.102
a_1	0.102	0.031	3.341	0.185

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