MICHIGAN STATE UNIVERSITY

CE 835 - ENGINEERING MANAGEMENT SYSTEM OF

PAVEMENT NETWORKS

PRFOJECT REPORT

by

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Submitted to: Dr. Gilbert Baladi

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Gilbert Y. Baladi, Ph.D, P.E,

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Michigan State University,

East Lansing, Michigan 48823

RE: Project Delivery of CE835 Pavement Management System for the District 5 of Louisiana State

Dear Dr. Baladi,

In the scope of CE 835 Management of Engineering Infrastructure Systems course project, Markovian optimization process is applied to Louisiana State (district 5) in order to evaluate five future rehabilitation and maintenance strategies of the network. Results of the analyses are detailed in this report.

Sincerely,

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1. ABSTRACT

In this report, a pavement management system was established for District 5 of Louisiana State. A network and project level evaluation was conducted with respect to the scope of the CE 835 project regarding Management of Engineering Infrastructure Systems. In order to establish a pavement management system, the time dependent pavement condition and distress data of the pavement network and all maintenance and rehabilitation actions that were taken in the past were examined. For each pavement condition and distress type, the remaining service life (RSL) of each 0.1 mile long pavement segment along the network was estimated based on pre-determined threshold values. After determining the before and after treatment RSL values treatment transition matrices were generated to study the effects of the treatment. The data were also used as input to the stochastic Markovian process to determine the impact of various pavement preservation strategies on the longevity of the pavement network and to select an optimum strategy.

2. INTRODUCTION

Given the various pavement treatment alternatives, it is important to select appropriate and cost-effective pavement preservation alternatives to restore the pavement conditions and to eliminate or minimize the causes of its deterioration. The selection of such alternatives and their appropriate application time maximize the pavement service life (Brakey, 2000). However, the optimum selection of space, time, and preservation actions to maintain the pavement network within the given budgetary constraints, make the job of State Highway Agencies (SHAs) very difficult-(Dawson, 2012a).

A successful and integrated PMS houses all the activities of the road agency including financing , planning, scheduling, designing, constructing, assessing and preserving the pavement network (Baladi, Novak, & Kuo, 1991). One of the PMS definition states that PMS is a set of tools or methods that assist the decision makers in making cost-effective decisions. (AASHTO, 1993). Another definition of PMS is managing and controlling a wide range of activities for maximizing the benefit and decreasing costs by using the resources efficiently (Group, 1987). Also, one of the very old definition, of PMS is that of the AASHTO, 1985, which states that PMS is an established and documented procedure to systematically manage all pavement activities. (AASHTO, 1985).

2.1. Goal, Policy and Objectives

The main goal of this PMS is to preserve the pavement network in a cost-effective manner while providing the users with safe and smooth ride within the given constraints. Hence, the PMS must be flexible to be tailored to the need of the agency and its sets of constraints (Khattak, Baladi, Zhang, & Ismail, 2008).

Policy - The policy of this Road agency is to maintain an integrated database that assist the agency in making the right decisions at the right time to keep the pavement distresses level under the pre-determined threshold values specified in the objective part.

Objectives - The objectives of the PMS are to:

1. Establish inter and intra communication channels that assist the people to share their experiences.
2. Collect prevalent pavement condition and distress data and analyze and assess these collected pavement information for the District 5 of Louisiana State sections.

3. Maintain the pavement network in good condition and maximize the longevity of the network within the given constraints.
4. Keep the pavement conditions and distress levels below the threshold values listed in Table 1.

Table 1: Pavement Condition and distress threshold values (Source: (Khattak & Baladi, 2015))

Pavement Condition and Distress Type	Threshold values
IRI	200 (in/mi)
Rut Depth	0.5 (in)
Alligator Cracking	105.6 ft per 1/10th mile
Longitudinal Cracking	700 ft per 1/10th mile
Transverse Cracking	700 ft per 1/10th mile

2.2. Data Collection System

The data collection of the pavement network is very crucial step in establishing an engineering management system especially for determining the type and application of the treatments (Cafiso, Di Graziano, Kerali, & Odoki, 2002). Therefore, care should be taken while establishing and evaluating the various aspects of the data collection system. For example, the data collection frequency, data sampling, the sample size, and the selected representative sample affect the accuracy of the collected data (Zimmerman, 1995). There are several ways to collect pavement condition and distress data, fully automated, semi-automated and manual (Dawson, 2012a). Data collection procedures are detailed in the FHWA study. (FHWA, 1995). Finally, the quality control procedures used to check the accuracy and consistency of the collected data plays a major role in determining the data quality. In this project, the provided PMS data obtained from the Louisiana DOT for District 5 was used to develop a pavement management system. Before the data analyses were commenced, the data were subjected to two data acceptance criteria tests as stated in the next section.

2.4. Pavement Condition and Survey Data

The pavement condition and distress and the pavement treatment data of District 5 of the state of Louisiana (Dawson, 2012b) were used to develop an engineering management system and conduct project and network level analyses. The historical distress data consists of 4 main distress types: (a) Pavement roughness is defined as irregularities in the pavement surface which adversely affect the ride quality. (b) Rutting is simply introduced as surface depressions in the wheel paths and is measured in inches. (c) Transverse cracks are perpendicular to the pavement's centerline direction. (d) Longitudinal cracks are parallel to the pavement's centerline. Lastly, (e) fatigue cracks are a series of interconnected cracks caused by repeated load applications. All cracking data are reported in terms of linear feet per 0.1 mile. Over time, the sections of the pavement network were subjected to the various treatment actions listed in Table 2:

Table 2: Treatment Data on Pavement Network

Pavement Section		Treatment Type	Year	Project Cost ($)	Length (mi)
Route Number	**Control Section**				
LA 134	161-09-1	Chip Seal	200 2	49106	2.7
LA 3181	818-13-1	Chip Seal	200 3	48421	2.8
LA 545	308-08-1	Chip Seal	200 2	55039	3.6
LA 144	318-01-1	Double Chip Seal	200 2	106787	5.2
LA 133	163-02-1	HMA Overlay (Less than 2.5 inch)	200 4	817689	3.2
LA 3051	834-17-1	HMA Overlay (More than 2.5 inch)	200 4	1326819	3.8
LA 15	026-09-1	Mill and Fill (Less than 2.5 inch)	200 4	1914147	3.925

US 80	001-08-1	Mill and Fill (More than 2.5 inch)	200 4	1352179	0.8
					26.025

2.3. Data Acceptance Criteria

In general, the collected pavement condition and distress data cannot be fully analyzed unless they meet the two data acceptance criteria detailed below (Khattak & Baladi, 2015).

Three Data Points Criterion

In order to model the pavement condition and distress data as nonlinear functions of time using equations 1 through 3, the database should have a minimum of three data points after treatment and/or three data points before treatment. The three generic equation forms used in the analyses of the time dependent pavement condition and distress are stated below.

$$\boldsymbol{International\ Roughness\ Index\ (IRI)} = \propto \times \exp(\beta t) \quad [1]$$

$$\boldsymbol{Rut\ Depth\ (RD)} = \gamma \times t^{w} \quad [2]$$

$$\boldsymbol{Crack} = \frac{k}{1 + exp[-\theta(t-\mu)]} \quad [3]$$

where $\propto, \beta, \gamma, w, \theta$ and μ are regression parameters and t is the elapsed time in years

The three mathematical functions are based on the observation of the accumulated pavement condition and distress over time (ME-PDG, 2004; Meyer, Yung, & Ausubel, 1999). Pavement roughness as expressed by IRI increases exponentially over time. Pavement rutting occurs after construction and its rate decreases over time. Thus, a power function is used to model the rut depth data. Lastly, crack propagation can be observed in three stages, exponentially at early pavement ages, linearly at mid age, and approaching saturation stage at a later age. . The 3 stages are typically modeled using an S-shaped curve (logistic function). Based on the number of data points available in the database and on pavement age, either logistic function or logistic function components (exponential, linear and power function) can be used to model the cracking data.

"Positive Slope" Criterion:

In general, pavement deteriorates over time. However, the available data of some pavement sections indicate that the pavement is healing itself over time without the application of treatment. The reasons for such pavement condition and distress data could be related to data variability, environment (temperature in particular), the distress survey technique, and errors in the data logging. In such scenario, the data cannot be analyzed and the remaining service life cannot be calculated. Thus, any data set showing improvement in the pavement condition and distress over time without the application of treatments are not included in the analyses.

2.2. Current Pavement Condition and Distress

The DI can be defined as an indicator to show pavement condition and distresses. A rating system was needed to be established to indicate rate of impact on the distresses types and then distresses indices were calculated. The disadvantage of using distress indices (DI) parameter is that it does not show the performance of the pavement; in other words, it does not indicate the specific information regarding distress types. It can be given an example so that a GPA (a combined grade index) of 3.5 does not indicate the grade points in Physics or Chemistry. A student may score 1.0 in one course and 4 in another and his GPA will be 2.5. The weight of the various courses in the GPA is the number of credits for each course.

2.3. Remaining Service Life Procedure and Analysis

The remaining service life (RSL) is defined as the number of years between the last distress survey date and the time when the pavement condition and distress reach the threshold values (Dawson, 2012a). The RSL is necessary to eliminate the disadvantages of the distress indices of the pavement network (Baladi, Novak, & Lyles, 1985).

The RSL of each 0.1 mile long pavement segment was calculated using either equations 4, 5, or 6 depending on the distress type and pavement condition. The RSL expresses the number of years between the data collection year and the time where pavement preservation must be applied (Dawson, 2012a).

$$\boldsymbol{RSL_{IRI}} = \frac{\ln\left(\frac{IRI_{threshold}}{\propto}\right)}{\beta} \leq DSL \qquad [6]$$

$$\boldsymbol{RSL_{Rut}} = \left(\frac{Rut_{threshold}}{\gamma}\right)^{w} \leq DSL \qquad [7]$$

$$\boldsymbol{RSL_{Cracking}} = \mu - \frac{\ln\left(\frac{k}{Crack_{threshold}} - 1\right)}{\theta} \leq DSL \qquad [8]$$

where $\propto, \beta, \gamma, w, \theta$ and μ = regression parameters and DSL = design service life,

An example of estimation for RSL is available in Appendix A. The RSL is an important indicator of the longevity of the pavement sections and the network. For each pavement section, five RSL values before and five RSL values after treatment can be calculated depending on data availability.

3. Optimization and Strategies

3.1. Treatment Transition Matrix

Before the development of the Treatment Transition Matrices (T^2Ms), the RSL values were divided into 5 brackets (one through 5) or five condition states. The division or the range in the RSL value in each bracket is based on remaining service lives. In order to explain T^2M, the following example can be used. In order to develop T^2Ms, remaining service lives were calculated based on the formulas (different for each distress type) mentioned in remaining service lives section. After estimating RSL values for each BMP of corresponding section, number of RSL bracket range and corresponding percentages were tabulated. Pavement network is a huge system and it is very difficult to estimate RSL years by using excel (like Appendices A). Therefore, Matlab algorithm developed by Gopikrishna (2015) was used to get RSL values, so transition matrices for the whole network. The regression parameters for rut distress, which are needed to calculate RSL, were compared between excel and Matlab algorithm in Appendices B. The final T^2Ms for each treatment type are available in the Appendices C section.

3.2. Optimum Strategy

Total mileage of the network was 26.025 mile. The limitation of the budget was $20000 for each 0.1 lane-mile in the network; therefore, the budget of $5205000 was allowed to use for the entire pavement network system. Five treatment strategies were established based on the sections of pavement network showing different distresses types. Eight treatment types; reconstruction, thick or thin HMA overlay, thick or thin mill and fill, single chip seal, double chip seal and crack seals were considered in developing the five strategies.

Markovian decision process (optimization) was used to determine best treatment strategy over the pavement network. The percent of RSL values before the treatment are entered and initial RSL value is automatically calculated for the network system and total RSL change is calculated based on the RSL values after the treatment at the transition matrices after changing percent treatment type that will be applied.

Five treatment strategies were developed. These strategies including the percent of the treatment type were developed by considering the effect of the distresses on the pavement network and treatment – distresses relationship. Also, the care was taken into the budget limitation on the treatments which is $20000 for each 0.1 lane-mile in the network.

Table 3: Treatment Strategies

Treatment Types	Strategies (Treatment %)				
	1	2	3	4	5
Reconstruction	0.5	0.0	0.0	0.0	**0.0**
Thick HMA Overlay	3.0	3.0	4.0	5.0	**4.0**
Thin HMA Overlay	3.0	4.0	4.0	5.0	**4.0**
Thick MF	3.0	4.0	3.0	2.0	**2.0**
Thin MF	3.0	3.0	3.0	2.0	**2.0**
Double Chip Seal	0.0	0.0	0.0	0.0	**5.0**
Single Chip Seal	9.0	9.0	9.0	9.0	**10.0**
Crack Sealing	1.0	1.0	1.0	2.0	**5.0**

Based on the average RSL of the flexible network in years, the strategy 5 was the optimum strategy with respect to highest remaining service life. Initial service life was 7.9 for the pavement network. The table and plot below indicated the final remaining service lives for each strategy and RMS change over the years, respectively.

Table 4: RSL change for each treatment strategy

Strategy	1	2	3	4	5
Initial RSL	7.90	7.90	7.90	7.90	7.90
Steady State RSL	13.98	14.21	14.31	14.42	14.44
RSL change	6.08	6.31	6.41	6.52	6.54

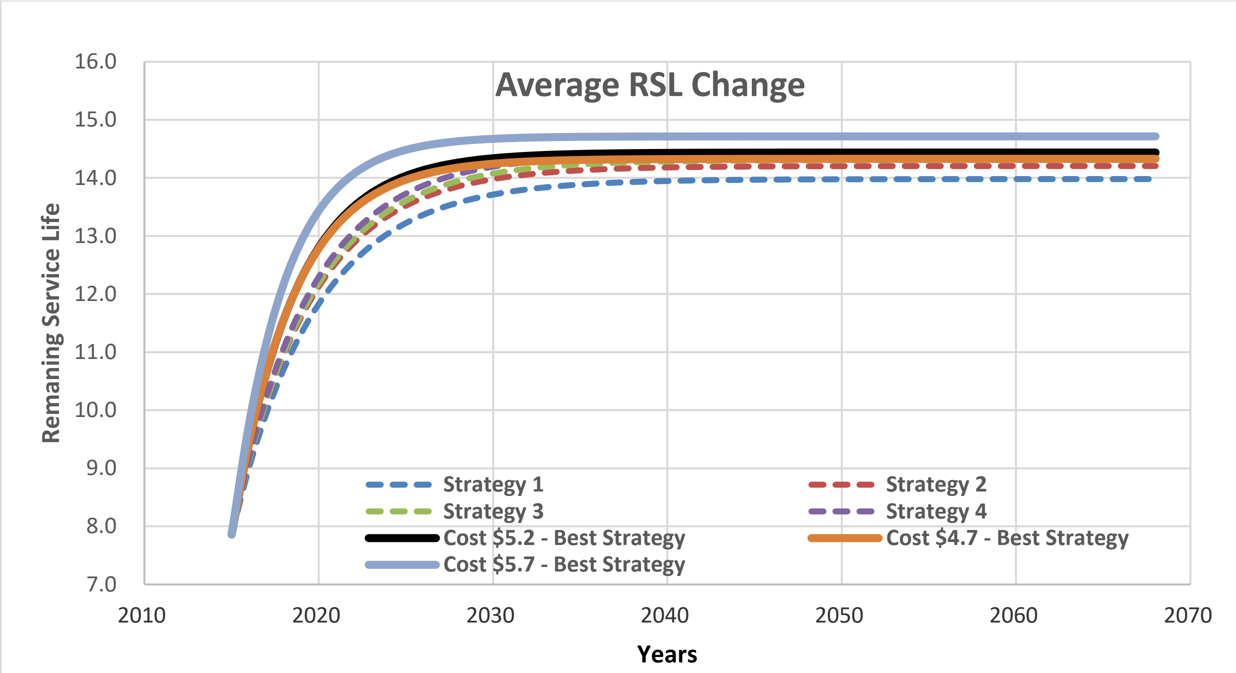

Figure 1: Average RSL Change for Each Treatment Strategy

In addition to 5 strategies for the $5.2 million budget, the best strategies for both $4.7 million and $5.7 million are plotted to indicate the effect of budget on RSL in the Figure 2. Since the treatment strategy 5 gave the highest RMS life within the budget limitation, strategy 5 was selected as optimum strategy for this pavement network. There is not much effect on the RSL change with 10% percent budget change with two direction. Even almost same RSL changes are obtained for the actual budget and 10% reduction at the actual one. The strategy for $4.7 million budget should also be considered for the maintenance strategy.

RSL change for different RSL year categories with first five (5) years after the strategy applied is plotted as below plot. From the plot, it can be seen that over the years remaining service life of the pavement network especially for 0-2 year's category decreases dramatically because of the improvement of the distresses in the network. RSL increases and it is reflected as increase in the number of occurrence at bigger RSL year's categories.

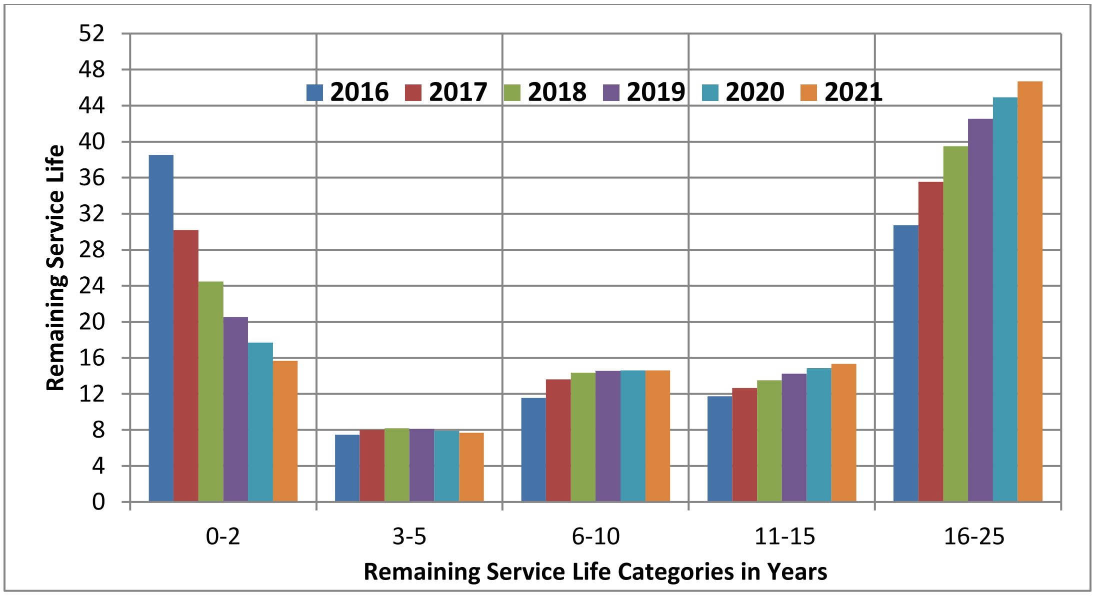

Figure 2: RSL change for the best strategy

The effectiveness of distresses on the sections after the treatment can be shown in the column plot below. The distribution is based on the number of pavement segments for each section.

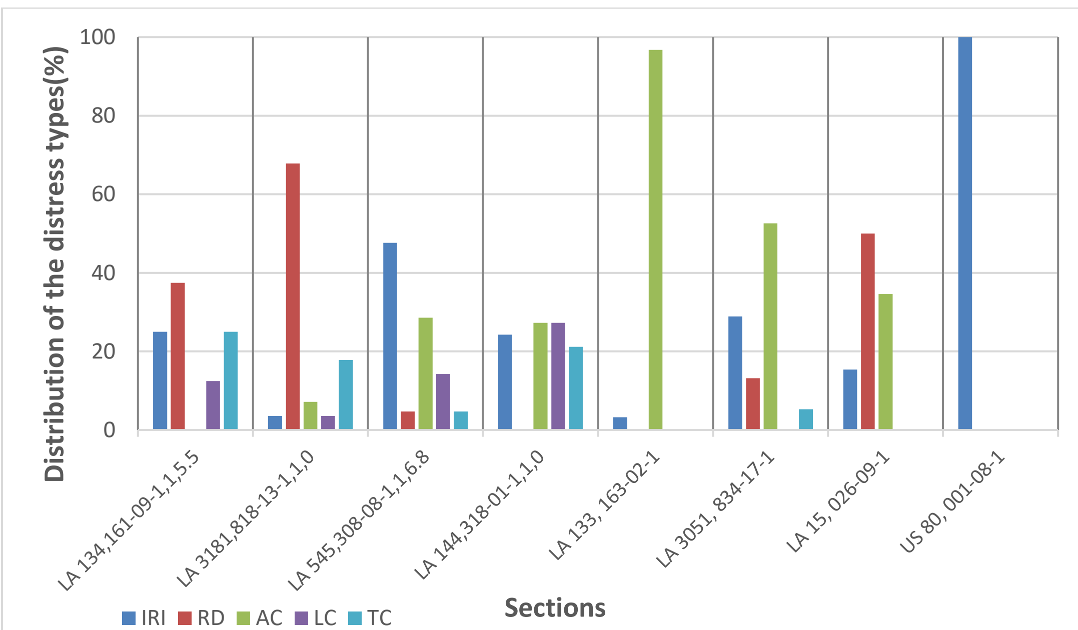

Figure 3: Distribution of the treatment network (%)

The figure above is important because proper treatment types for the future can be selected based on the pavement responds after corresponding treatment type with respect to distresses type. For instance, since chip seal treatments do not increase structural capacity, this treatment will be used for functional distresses such as IRI. However, the sections having structural distresses such as any of the cracking types will have overlay or mill and fill treatment. The treatments for the sections based on the Figure 3 can be summarized as below:

Table 5: Treatment types for the sections

Pavement Section		Treatment Type
Route Number	**Control Section**	
LA 134	161-09-1	Single Chip Seal
LA 3181	818-13-1	Single Chip Seal
LA 545	308-08-1	Single Chip Seal
LA 144	318-01-1	Crack Sealing + Double Chip Seal
LA 133	163-02-1	Crack Sealing + Thin HMA Overlay
LA 3051	834-17-1	Crack Sealing + Thick HMA Overlay
LA 15	026-09-1	Thin Mill and Fill
US 80	001-08-1	Single Chip Seal

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APPENDICES

A. An example (Louisiana State, District 4, thick HMA Overlay, LA 2, 083-01-1) of fitting mathematical functions for calculating RSL, SL, SLE (distress of IRI)

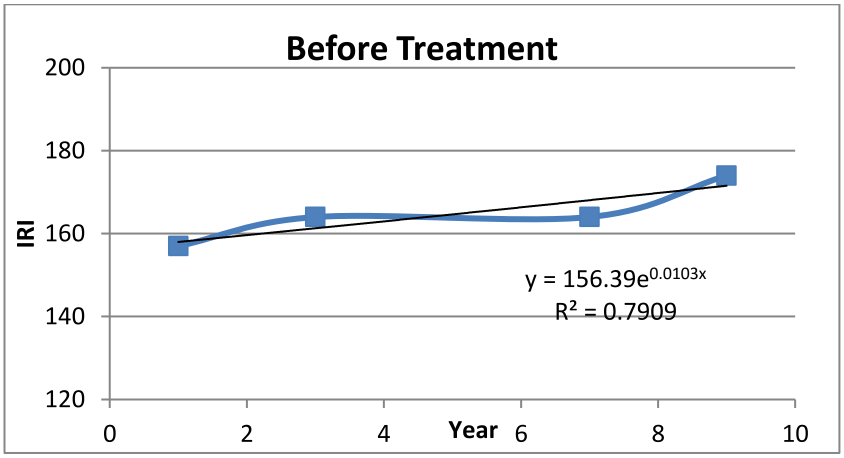

Figure 4: IRI equation fit before the treatment (LA 2,083-01-1,1,0-2 - 3.7 BMP)

Threshold = 200, RSL = ln(200/156.39)/0.0103 = 24 year

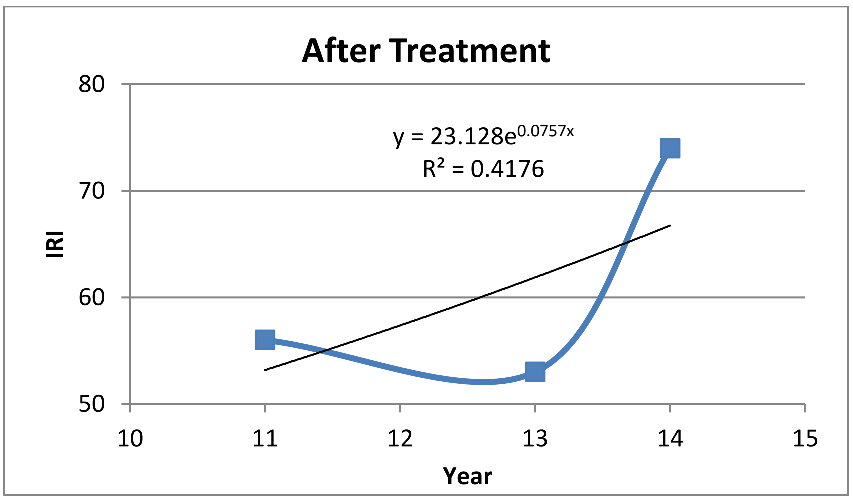

Figure 5: IRI equation fit after the treatment (LA 2,083-01-1,1,0-2 - 3.7 BMP)

Threshold = 200, SL = ln(200/23.128)/0.0757 = 28 year

SLE = SL – RSL = 4 year

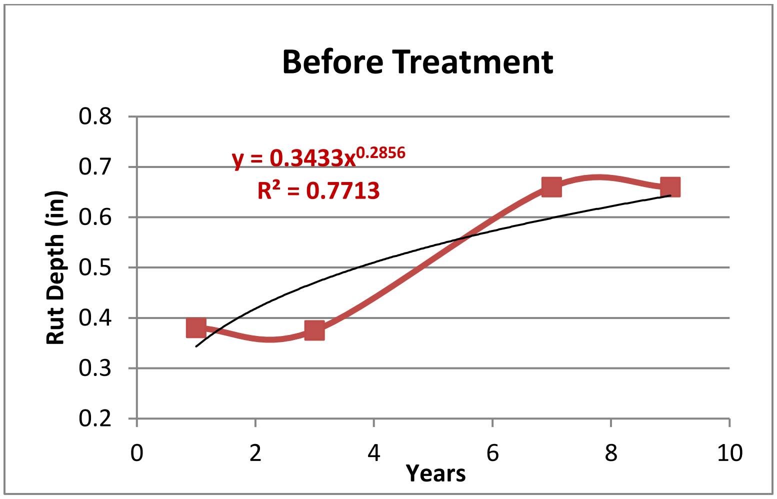

Figure 6: Rut equation fit before the treatment (LA 2,083-01-1,1,0-2 – 0.1 BMP)

Threshold = 0.5 in, RSL = (0.5/0.3433)^(1/0.2856) = 4,

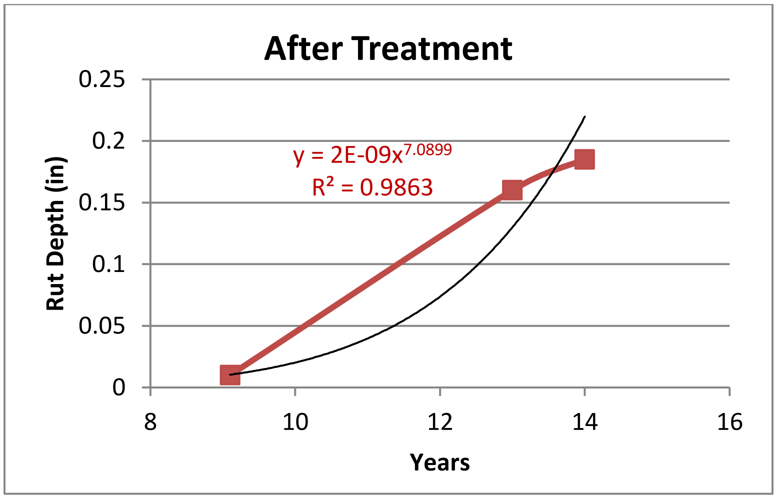

Figure 7: Rut equation fit after the treatment (LA 2,083-01-1,1,0-2 – 0.1 BMP)

Threshold = 0.5 in, SL = (0.5/ (2*10^-9))^(1/7.09) = 15 years,

SLE = SL – RSL = 11 years

Alligator and longitudinal does not meet the 3 point requirement. For transverse cracking, there are 3 points only before the treatment:

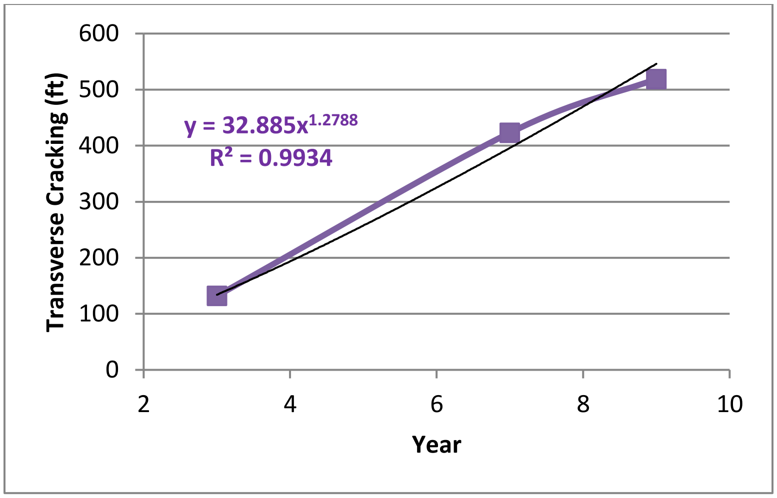

Figure 8: Transverse equation fit after the treatment (LA 2,083-01-1,1,0-2 – 1.4 BMP)

B. Excel vs. Matlab Comparison

Table 6: Regression parameters (rut) calculated from Excel and Matlab (LA 2,083-01-1,1,0-2)

BMP of 0.1 mile segment	Excel Fit		Matlab Fit		Excel Fit	Matlab Fit
	Power function parameters		Power function parameters		Before Treatment	
	α	β	α	β	RSL	Structural Period
0	0.3736	0.2400	0.3736	0.2400	3	3
0.1	0.3433	0.2856	0.3433	0.2856	4	4
0.2	0.2706	0.2997	0.2706	0.2997	8	8
0.3	0.3156	0.2788	0.3156	0.2788	5	5
1	0.3492	0.1945	0.3492	0.1945	6	6

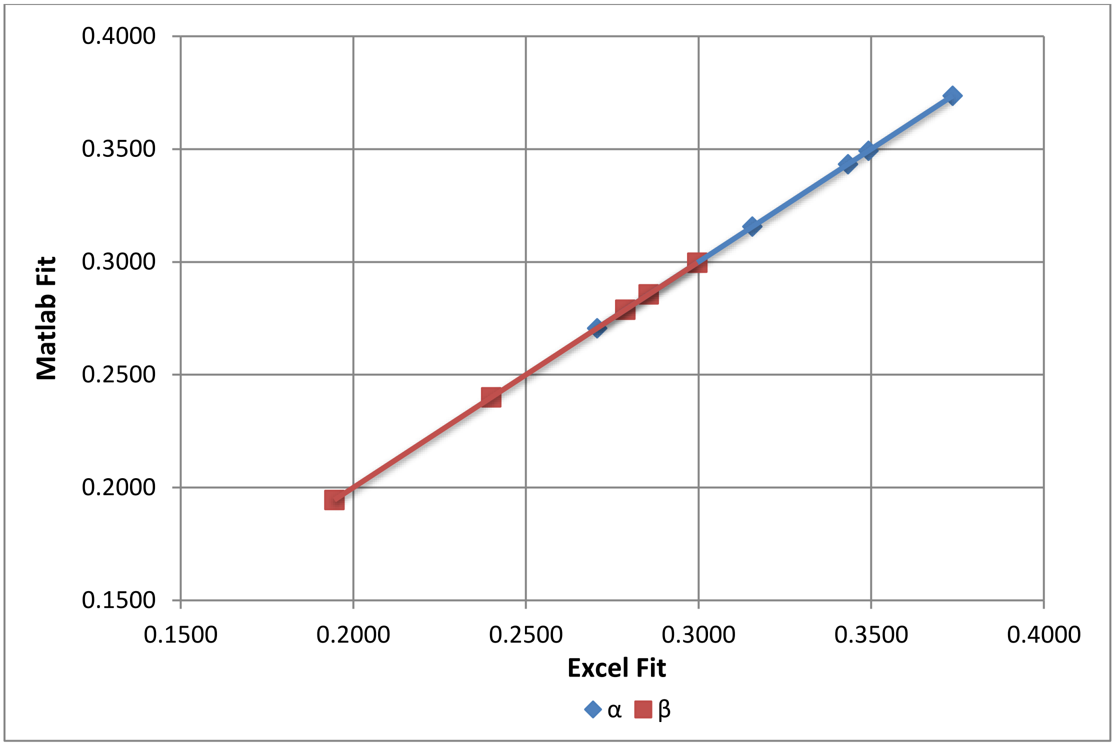

Figure 9: Regression parameters plot for excel and Matlab fit

C. OPTIMIZATION – T^2M

- Louisiana State, District 5, Single Chip Seal T^2M

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: condition/distress causing the minimum RSL												
	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	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 standard error of each RSL bracket							
A	1	0 to 2	383	63		**40**	111	131	44	57	4	8	9
B	2	3 to 5	57	9		2	**5**	16	9	25	4	10	14
C	3	6 to 10	30	5		1	2	**5**	7	15	4	7	15
D	4	11 to 15	34	6		0	0	13	**5**	16	2	2	15
E	5	16 to 25	105	17		2	0	5	18	**80**	2	-2	18
F	Total		609	100		45	118	170	83	193	4	6	11

- Louisiana State, District 5, Double Chip Seal T^2M

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: condition/distress causing the minimum RSL												
	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	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 standard error of each RSL bracket							
A	1	0 to 2	36	55		**10**	1	7	8	10	7	10	11
B	2	3 to 5	4	6		0	**1**	0	0	3	6	12	16
C	3	6 to 10	4	6		0	0	**1**	1	2	7	8	16
D	4	11 to 15	3	5		1	0	1	**0**	1	1	-3	10
E	5	16 to 25	19	29		0	0	4	2	**13**	3	-3	17
F	Total		66	100		11	2	13	11	29	6	5	13

- Louisiana State, District 5, Thin HMA Overlay T^2M

Row designation	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: condition/distress causing the minimum RSL												
	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: Number	0.1 mile pavement segments: Percent	Average standard error	1 0 to 2	2 3 to 5	3 6 to 10	4 11 to 15	5 16 to 25	Treatment life	Service life extension	RSL
						Average standard error of each RSL bracket							
A	1	0 to 2	28	90		**0**	3	6	3	16	8	14	15
B	2	3 to 5	0	0		0	**0**	0	0	0			
C	3	6 to 10	1	3		0	0	**0**	0	1	8	13	21
D	4	11 to 15	2	6		0	1	0	**0**	1	6	-1	12
E	5	16 to 25	0	0		0	0	0	0	**0**			
F	Total		31	100		0	4	6	3	18	7	13	15

- Louisiana State, District 5, Thick HMA Overlay T^2M

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: condition/distress causing the minimum RSL												
	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	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 standard error of each RSL bracket							
A	1	0 to 2	47	89		**0**	10	8	3	26	9	13	14
B	2	3 to 5	1	2		0	**0**	0	0	1	10	17	21
C	3	6 to 10	2	4		0	0	**0**	0	2	10	13	21
D	4	11 to 15	3	6		0	0	0	**0**	3	10	8	21
E	5	16 to 25	0	0		0	0	0	0	**0**			
F	Total		53	100		0	10	8	3	32	9	13	15

- Louisiana State, District 5, Thin Mill and Fill T^2M

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: condition/distress causing the minimum RSL												
	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	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 standard error of each RSL bracket							
A	1	0 to 2	75	64		**0**	0	14	19	42	8	15	16
B	2	3 to 5	4	3		0	**0**	1	0	3	8	13	17
C	3	6 to 10	8	7		0	0	**0**	1	7	8	12	20
D	4	11 to 15	22	19		0	0	1	**3**	18	8	6	19
E	5	16 to 25	8	7		0	0	1	0	**7**	8	-2	19
F	Total		117	100		0	0	17	23	77	8	12	17

- Louisiana State, District 5, Thick Mill and Fill T^2M

Row designation	Column designation												
	A	B	C	D	E	F	G	H	I	J	K	L	M
	Condition/distress type: condition/distress causing the minimum RSL												
	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	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 standard error of each RSL bracket							
A	1	0 to 2	359	77		**0**	6	115	99	139	8	13	14
B	2	3 to 5	26	6		0	**0**	4	6	16	9	13	17
C	3	6 to 10	16	3		0	0	**3**	4	9	9	8	16
D	4	11 to 15	32	7		0	0	1	**3**	28	10	6	19
E	5	16 to 25	35	7		0	0	2	4	**29**	10	**-2**	19
F	Total		468	100		0	6	125	116	221	9	11	15