Development of Treatment Performance Models for Flexible Pavements

A Thesis

Presented to the

Graduate Faculty of the

University of Louisiana at Lafayette

In Partial Fulfillment of the

Requirements for the Degree

Master of Science

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Fall 2013

Development of Treatment Performance Models for Flexible Pavements

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Acknowledgments

At first I want to thank my supervisor Dr. Mohammad Jamal Khattak. Without his idea, advice and impulse, it would not be possible for me to complete this thesis.

Special thanks go to Dr. Gilbert Baladi, who has provided us very useful software for data compilation. I would like to thank Mohammad Abdullah Nur too who has given his time, idea and full support during my two years research life in this school.

I finally want to dedicate this thesis to my parents Mr. and Mrs. Mohammad Habibur Rahman Bhuyan for their support and endless motivation.

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Chapter 1: Introduction

1.1 Background

It is very important to preserve the roads that are already built in Louisiana by several types of remedial maintenance programs. This is because that if the roadways are not preserved, it will eventually lead to the replacement of the pavement which is much more expansive than remedial maintenances or treatments. There are several types of treatments which can be applied on different stages of the life of a pavement. These treatments keep pavement alive, increases its life and delays the replacement of the pavement. Performance models of these different treatments are hence required to find the most cost-effective treatment and the application time for any particular pavement.

The Louisiana Department of Transportation and Development (LADOTD) operates approximately 18,000 roadway miles of roadways. These roadways consists of Flexible Pavements (ASP), jointed concrete pavements (JCP), composite pavements (COM) and continuously reinforced concrete (CRC) pavements. These roadway sections deteriorate over time due to increased traffic loads, environmental factors and aging.

Considerable financial resources has been spent by LADOTD on various rehabilitation and maintenance treatment programs. Such treatments include, but are not limited to, Chip Seal, Crack Seal, Micro surfacing, thin and thick overlays, rubblize and overlay, and structural overlays, patching and whitetopping. But a full scale performance assessment and cost-effectiveness analysis were not conducted till now for various treatments which would provide LADOTD the leverage of selecting the most cost-effective treatments.

There are five major type of distresses in all types of pavements called the International

Roughness Index (IRI), Rut, Fatigue Cracking, Transverse Cracking and Longitudinal Cracking. Treatment performance models include the performances of these five types of distresses for various treatments.

LADOTD initiated a research project entitled "Development of Cost-effective Pavement Treatment Selection and Treatment Performance Models" to develop Treatment Performance Models for various treatments (Project No: 10-4P). This study deals with the development of treatment performance models for predicting aforementioned distress types for Overlay, Chip Seal, Micro surfacing and Replacement of Flexible Pavements.

1.2 Objective and Scope of this Research

The objective of this research is to develop all distress models including IRI, Rut, Fatigue Cracking, Transverse Cracking and Longitudinal Cracking for Overlay, Chip Seal and Micro surfacing treatments and Replacement of Flexible Pavements. The developed models will facilitate the determination of pavement deterioration over time, treatment lives and remaining service lives of a roadway section.

In order to accomplish the objectives of the study, various LADOTD databases including Pavement Management System (PMS) distress database, Pavement Historical data, Pavement Preservation Data, Material Testing System (MATS), Tracking of Projects (TOPS), Letting of Projects (LETS) were thoroughly searched. From National Climatic Data Center (NCDC) Database, Temperature and Precipitation data is taken and Climatic Indices are developed (Low Temperature Index, Temperature Index and Precipitation Index). Traffic data (ESAL) is taken from LADOTD mainframe Database. From all these databases, 972 roadway sections was selected which has sufficient data to build models for all treatment types.

Roadway sections treated with same treatment were segregated and regression analysis is performed for each specific group of projects to develop different distress models for different treatment types.

1.3 Organization of the Thesis

This thesis is organized in five chapters. The first chapter gives a small background and introduction. The second chapter provides a brief literature review of previous distress models and descriptions of treatments. The third chapter illustrates the process of data collections and environmental indexes developed in this study. The fourth chapter will deliver the models and model behaviors and the fifth chapter includes conclusions and recommendations.

Chapter 2: Literature Review

2.1 Background

Any pavement can have five major kind of distress. These are IRI, Rut, Fatigue Cracking, Transverse Cracking and Longitudinal Cracking. This section will describe these five distresses' definitions and a brief literature review of their models. Also, a definition of four major types of treatments will be presented at the end.

2.2 Review of Distresses and their Performance Models

2.2.1 IRI Models

IRI is an index that implies pavement roughness in terms of the number of inches per mile measured by a laser, mounted in a specialized van (ARAN). IRI values ranges from 50 to 250 inches/mile. University of Michigan conducted a research project in Brazil in the 1980s which initiated the development of the international roughness index (IRI) (*1*). Over the years, researchers have successfully applied the IRI for modeling the smoothness of a pavement (*2,3,4,5,6*). Surface age and traffic were used as predictor variables by Hein and Watt (2005) (*7*) in an effort to built empirical prediction model for pavement performance. 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. (1998) (*8*) and Ozbay and Laub (2001) (*9*). Roughness progression in HMA overlay pavement shows distinct trends in similar climatic environments as suggested by Perera and Kohn (2001) (*10*). A combination of field and experimental data was used by Prozzi and Madanat (2004) (*11*) 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. In this study, the treatment performance curve for IRI was also assumed to be an exponential model as shown in Equation 1:

$$IRI = \alpha \exp^{t\beta} \tag{1}$$

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

2.2.2 Rut Models

Rut is the vertical depression of the pavement along the wheel path measured in inch. It is as depicted in Figure 1.

Figure 1: Typical Rut in a Flexible Pavement (*12*)

There are generally three distinct stages for the rutting behavior of pavement materials under a given set of material, load and environmental conditions and they are primary, secondary and tertiary stages (13). 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.

$$Rut = \lambda t^{\beta} \tag{2}$$

The above equation can be written as:

$$ln(Rut) = ln(\lambda) + \beta\, ln\, t \tag{3}$$

Equation 3 became the basis for the regression analysis in this study.

2.2.3 Cracking Models

There are three types of Cracking: Fatigue Cracking, Transverse Cracking and Longitudinal Cracking. Fatigue Cracking (FC) is the cracking due to age which looks like alligator skin measured in square feet. Transverse Cracking (TC) is the cracks of pavement perpendicular to its length (measured in feet). Longitudinal Cracking is the crack of pavement along its length (measured in feet). Figure 2, Figure 3 and Figure 4 shows Fatigue, Transverse and Longitudinal cracking respectively.

Figure 2: Typical Fatigue Cracking (*12*)

Figure 3: Typical Transverse Cracking (*14*)

Figure 4: Typical Longitudinal Cracking (*12*)

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 vehicle (*15*). In addition to inducing roughness, the water seepage through the cracks and along with the debris accelerates the rate of deterioration of treatments and underlying pavement layers thus, reducing the pavement service life (*16*).

Cracking pattern in a pavement tends to follow logistic (S-shaped) function (*17,18*).

$$Crack = \frac{Max}{1 + exp^{(-X)}} \tag{4}$$

The Equation 4 can be written into the following form:

$$ln\left(\frac{Crack}{Max - Crack}\right) = X \tag{5}$$

Where,

$$X = a_o + a_1.x_1 + a_2.x_2 + a_3.x_3 + a_4.x_4 + ...$$

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.

$$ln\left(\frac{Crack+1}{Max-(Crack+1)}\right)=X \tag{6}$$

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

2.3 Treatment Types

As a treatment process of poor conditioned road, Hot Mix Asphalt Mixtures (Asphalt, Course Aggregate and Fine Aggregate) of definite thicknesses are applied on the roadway. This HMA layer is called as Overlay. Overlay ranges from 1.5 inch thickness to 7 inch thickness. Chip Seal is a pavement surface treatment that combines one or more layer(s) of asphalt with one or more layer(s) of fine aggregate. Micro surfacing is a mixture of polymer-modified asphalt emulsion, mineral aggregate, mineral filler, water and other additives, mixed and spread on a paved surface. Chip Seal or Micro surfacing can be given as one, two or three application (*19*). By Replacement, LADOTD means New Pavement. Figure 5, Figure 6, Figure 7 shows Overlay, Chip Seal, Micro surfacing respectively.

Figure 5: Overlay Treatment (*20*)

Figure 6: Chip Seal Treatment (*21*)

Figure 7: Micro surfacing Treatment (*22*)

Chapter 3: Data Collection and Project Selection

3.1 Pavement Distress Data

LADOTD's mainframe database contains the time-series pavement distress data. The section of the mainframe that contains reconstruction and rehabilitation dates is located in the tracking of projects system (TOPS). The pavement management system (PMS) data has been recorded every two years since 1995 by the automatic road analyzer (ARAN). All such data are reported every 1/10th of a mile based on a location reference system called as "control-section log-miles." The department has a numerical coding system for recording cost data and relating it to a segment of roadway. Each state highway is divided into smaller segments called "Controls" and each Control is divided further into smaller segments called "Section". The state project number usually consists of the control-section of the highway being worked on and a job number on that section. This 1/10th of a mile is also referred to as an element ID in the database.

3.2 Roadway and Project Selection

All roadways where different treatment projects were implemented were identified, with the help of pavement management system (PMS) office, project review committee (PRC), and district engineers. For this purpose, LADOTD database were searched including the PMS database, MATT), TOPS, 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.

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.), roadway classification (National Highway System, NHS (Interstate and others); State Highway System, SHS; and Rural Highway System, RHS), highway functional classification (arterial, collector, etc.) pavement performance data (distress data, i.e. rut, IRI) 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.). Highway functional classification is an important parameter in our analysis and LADOTD classifies the pavement network in six categories. Name of the classification and their assigned value based on priority in parentheses are as follows: Interstate (1), Principal Arterial (2), Minor Arterial (3), Major collector (4), Minor collector (5) and Local Road (9).

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 should have at least one data point just prior to treatment (BT) and three or more data points after treatments (AT) were selected for analysis.

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

3.3 Acceptance of Projects

Once the candidate projects have been identified, the following criteria have to be met for both the before-treatment (BT) and after-treatment (AT) time-series distress data to accept a pavement section (0.1 mile) within a project for use in the analyses. Any rejected pavement sections (BT, AT, or both) cannot be used to model pavement performance and are therefore kept away from the analysis.

Criteria 1- One point before treatment (BT acceptance): Distress value before treatment is important to identify the effectiveness of the treatment.

Criteria 2- Positive gain in distress based on the best-fit curve (AT acceptance): Decrease in the AT distress between the first and the last data points is likely the results of the application of maintenance actions that are not recorded in the available database. When the available AT condition data of a pavement segment produce negative slope/rate of regression model, that segment is excluded from the analyses. Negative regression parameters imply that the distress is "healing" with time and consequently the service life is infinite.

3.4 Climatic Parameters

Climatic parameters such as temperature and precipitation are the most important environmental factors that have considerable effects on the pavement distress. LADOTD does not have a complete database for climatic data, so it is deemed necessary to make a climatic database for this study. For this purpose, 20 weather stations encompassing Louisiana were selected based on data availability. The selection was made in a way to cover all part of Louisiana. Among the 20 weather stations from the 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 and daily precipitation value from year 2000 to

2010 were collected.

After collecting the climatic data it was necessary to interpolate data for each control section from nearby weather stations. The geographical latitude and longitude co-ordinate of each control section's beginning log-mile (BLM) were recorded from LADOTD 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 (*23*). 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.

Most researchers in the past had used freezing index (FI) as one of the parameters for predicting rut model (*13,24*). However, Louisiana's temperature seldom goes below freezing temperature, furthermore based on LTTP 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 is introduced to evaluate the effect of temperature (*25*). Unlike FI, TI represents the variation of temperature of a particular place over the year. Base temperature of 20°C (68°F) was used to find the TI. A negative one-degree day represents one day with a mean air temperature one degree below 20°C, a positive one-degree day indicates one day with a mean air temperature one degree above 20°C. 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 25°C on the first day and 22°C on the second and 17°C third days, the total degree days for the three-day period are (25-20) + (22-20)+ (17-20) = 4 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 8. The difference between the maximum and minimum points on the curve during one year is called the Temperature Index for that year.

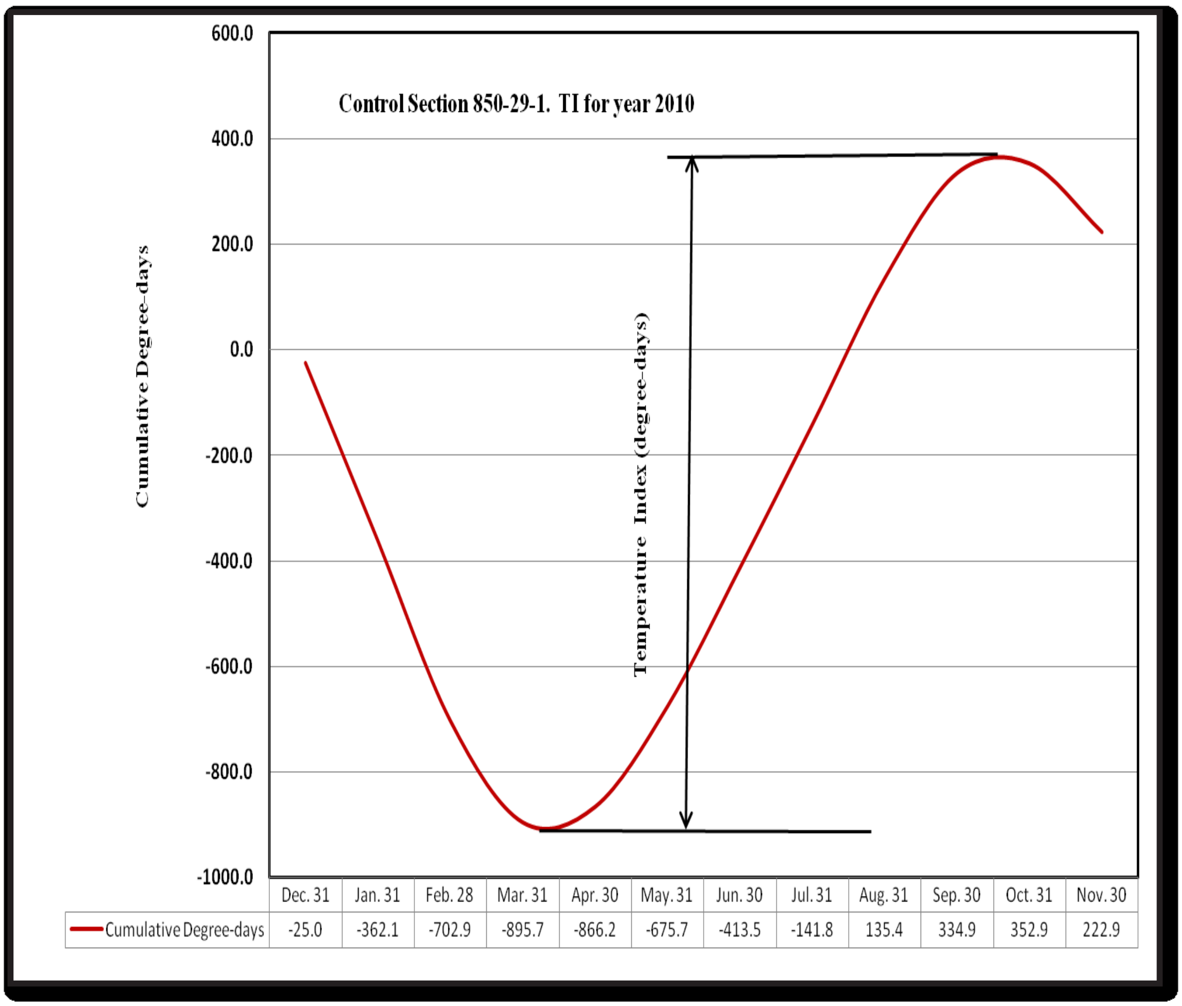

Figure 8: Determination of Temperature Index

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

$$LTI = \sum (4 - T_m), T_m \leq 39.2°F \qquad (7)$$

Where, LTI = Low Temperature Index, (°F-Days) in a year, and T_m= Mean Daily Temperature (°F).

For example, project 005-09-0033 is located in District 2 (southern part) has a LTI value of -55.72 (°F-Days) compared to LTI value of 109.02 (°F-Days) for project 025-08-0053 which is located in District 4 (northern part) for year 2000. This difference could easily contribute to performance of the pavement and must be considered while producing distress models.

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

$$PI= P. N_p \qquad (8)$$

Where PI is the precipitation index (in-days), P is the precipitation/year (in), and N_p 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.

Chapter 4: Treatment Performance Models

4.1 General

For Flexible Pavements, pavement distress prediction models were developed for overlay, Chip Seal and Micro surfacing treatments. The following section provides the discussion of various developed models. About 972 projects were initially identified on which some type of pavement treatment was applied. It was found that 791 treatment projects had good performance and historical data. These projects have 1 distress data points before and 3 data points after the application of treatment.

4.2 Flexible Pavement with Overlay Treatment

4.2.1 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 were 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.

$$\ln(IRI) = a_0 + a_1 * \frac{1}{Fn} + a_2 * \frac{\ln(CESAL)}{T_H} + a_3 * TI + a_4 * CPI * t + \Delta \tag{9}$$

Where, IRI =International Roughness Index (in/mile), IRI_p = IRI value before treatment, CESAL = cumulative ESAL, T_H = thickness of HMA overlay, Fn = functional classification, TI = temperature index (Degree Fahrenheit-days), t = age of treatment (year), CPI =

cumulative precipitation index (in-days) and Δ = -0.5098 + 0.2448 ln(IRI $_{pp}$). Here, IRI_{pp} = Predicted value of IRI of the previous year. After the regression, the final form of the IRI was found to be:

$$IRI = \exp\left(\alpha * (3.331 - 0.2798 * \frac{1}{Fn} + 0.04755 * \frac{\ln(CESAL)}{T_H} + 0.0001478 * TI + 2.33E - 7 * CPI * t + \Delta\right) \quad (10)$$

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

The results of statistical analysis are shown in. Figure 9 shows the predicted versus the measured ln(IRI) values for overlay treatment on Flexible 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 10 illustrates the model behavior for few selected projects. From Figure 11, we can see that the error distribution of IRI is normal which an indication of good applicable model. Also, as from the Table 1, it is clear that all the variables are statistically significant at p-value ≤0.05.

Table 1: 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}

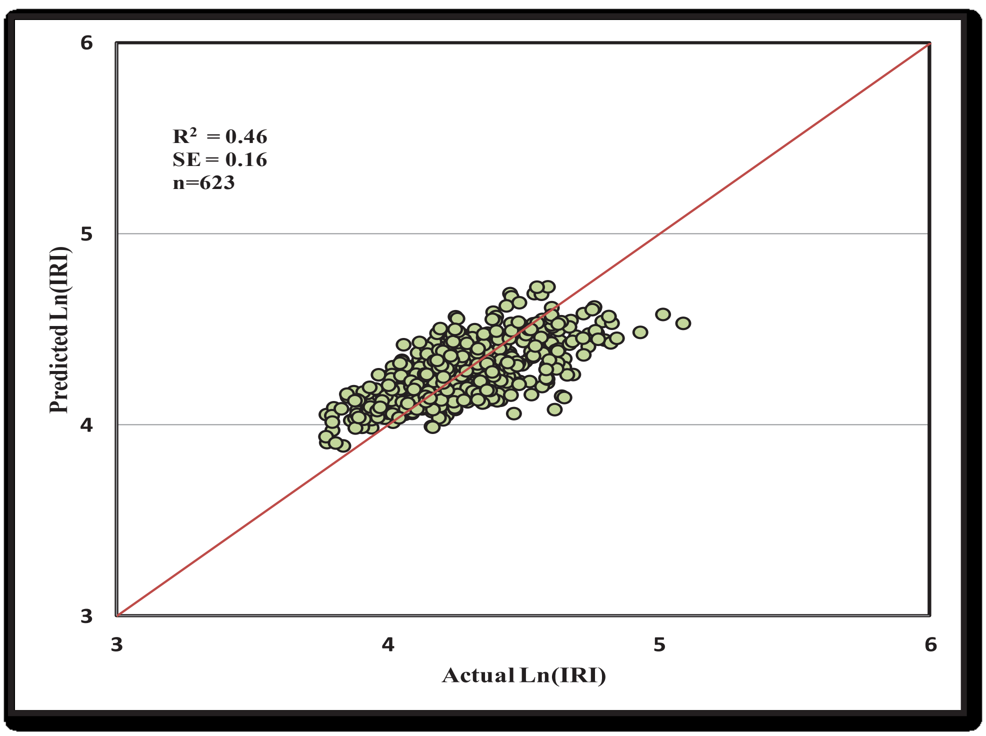

Figure 9: Predicted versus actual ln(IRI) for Flexible Pavement

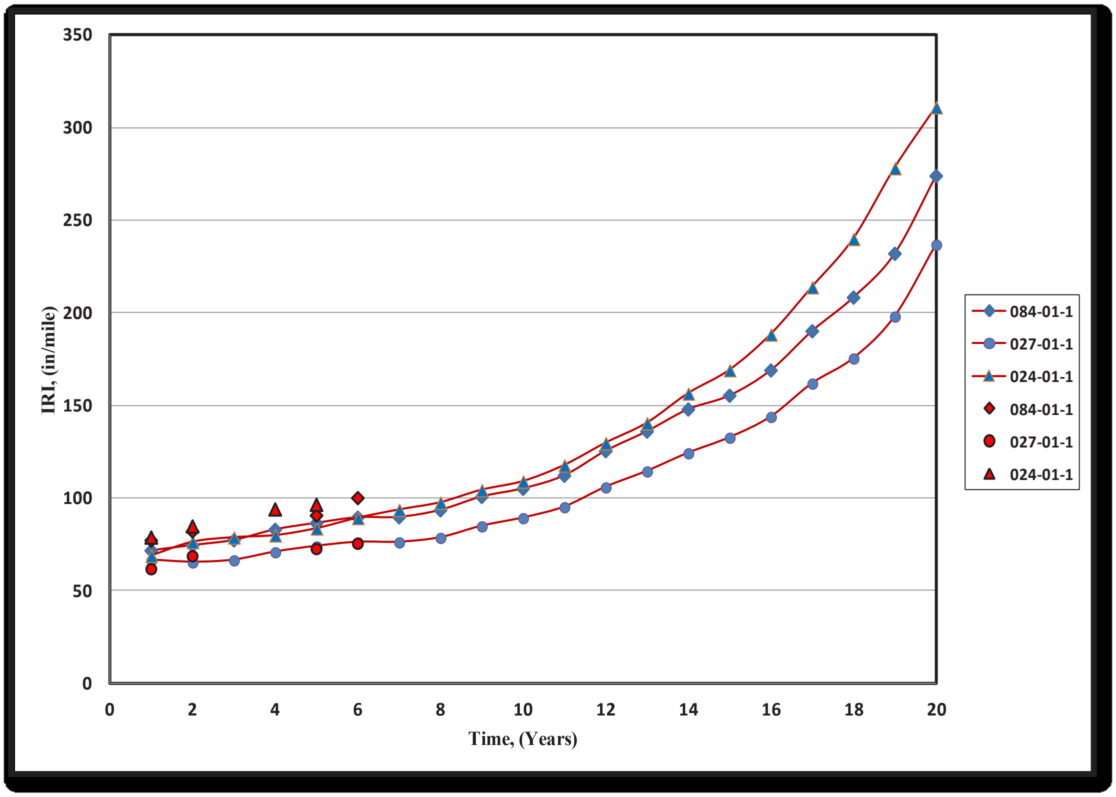

Figure 10: IRI Model behavior against measured IRI values for Flexible Pavement

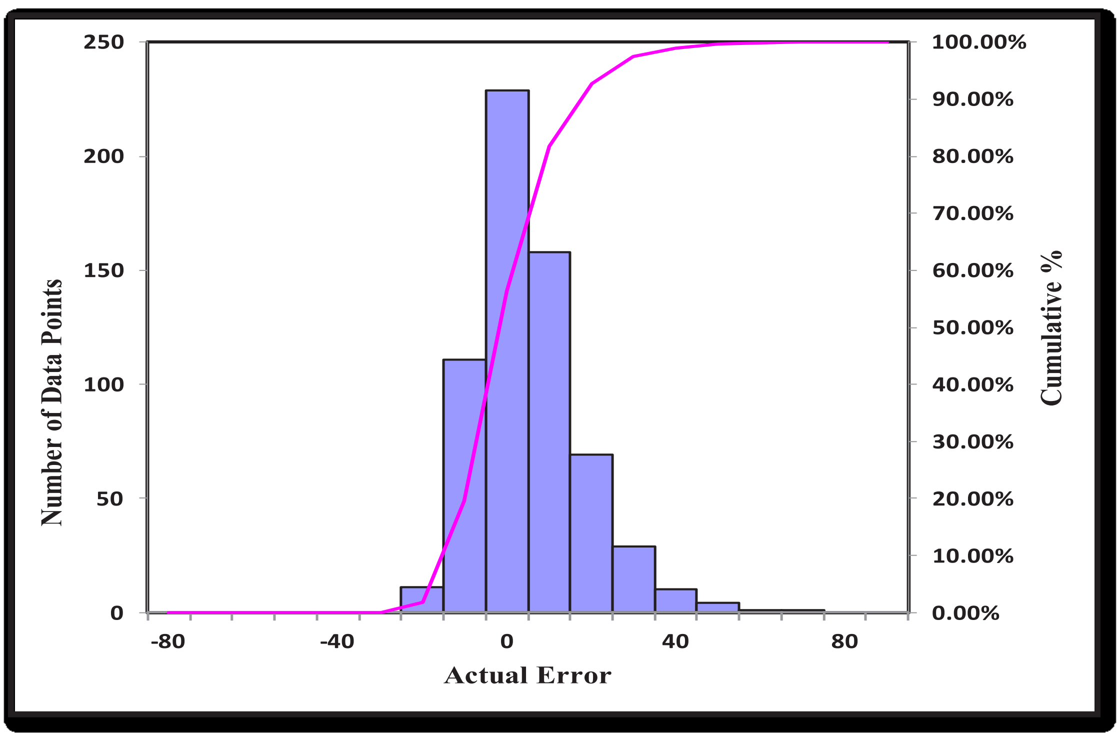

Figure 11: Actual error between measured and predicted values of IRI

4.2.2 Transverse Cracking Model

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:

$$\ln\left(\frac{TC+1}{Max-(TC+1)}\right) = a_o + a_1 * \left(\frac{1}{Fn}\right) + a_2 * \frac{\ln(CESAL)}{T_H} + a_3 * t \quad (11)$$

Where, TC = transverse cracking (ft/mile), Max = 10560 ft/mile, CESAL = cumulative ESAL, T_H = thickness of HMA overlay (in), Fn = functional classification, CLTI = cumulative Low Temperature Index (°F-days), CTI = cumulative Temperature Index (°F-days). The results of statistical analysis are shown in Table 2.

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

$$TC = \frac{10560}{1 + \exp^{-\left(-7.619 - 3.524 * \left(\frac{1}{Fn}\right) + 0.3375 * \frac{\ln(CESAL)}{T_H} + 0.6947 * t\right)}} - 1 \quad (12)$$

The predicted versus the measured *ln((TC+1)/(Max-(TC+1))* value for overlay treatment on Flexible Pavement is shown in Figure 12. 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. From Table 2, all the variables used in the models are statistically significant with p-value ≤0.05. Figure 13 depicts 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 14 shows actual error distribution of transverse crack and it shows random trend which is necessary for a good model.

Table 2: 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}

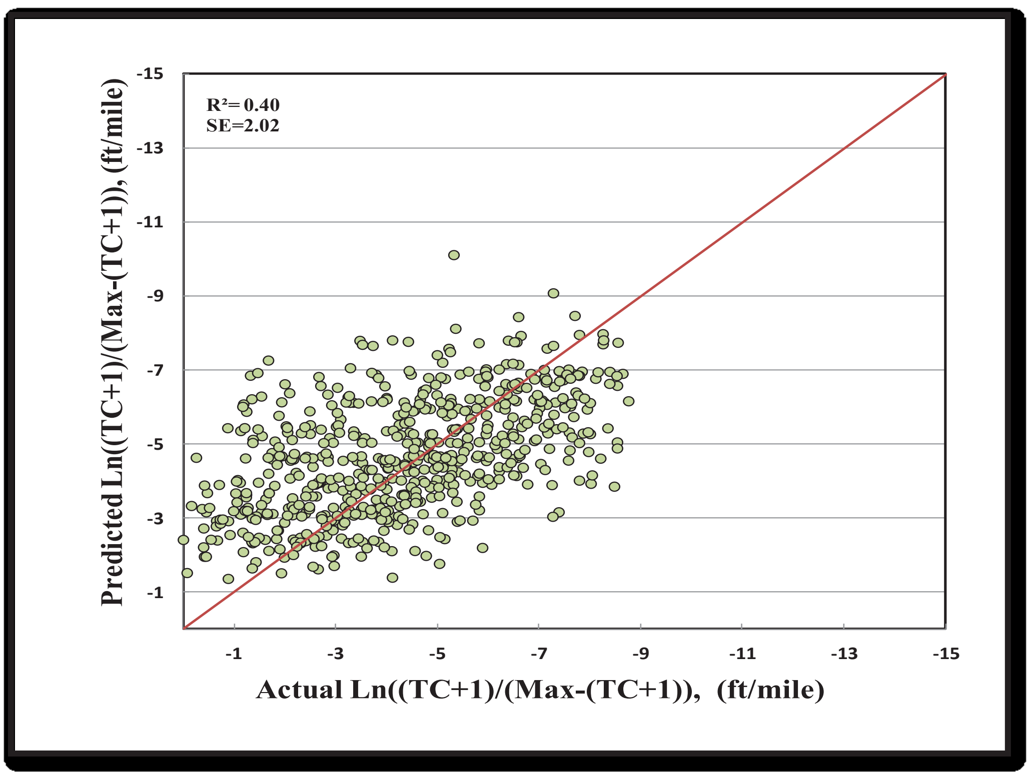

Figure 12: Predicted versus actual Ln((TC+1)/(Max-(TC+1))

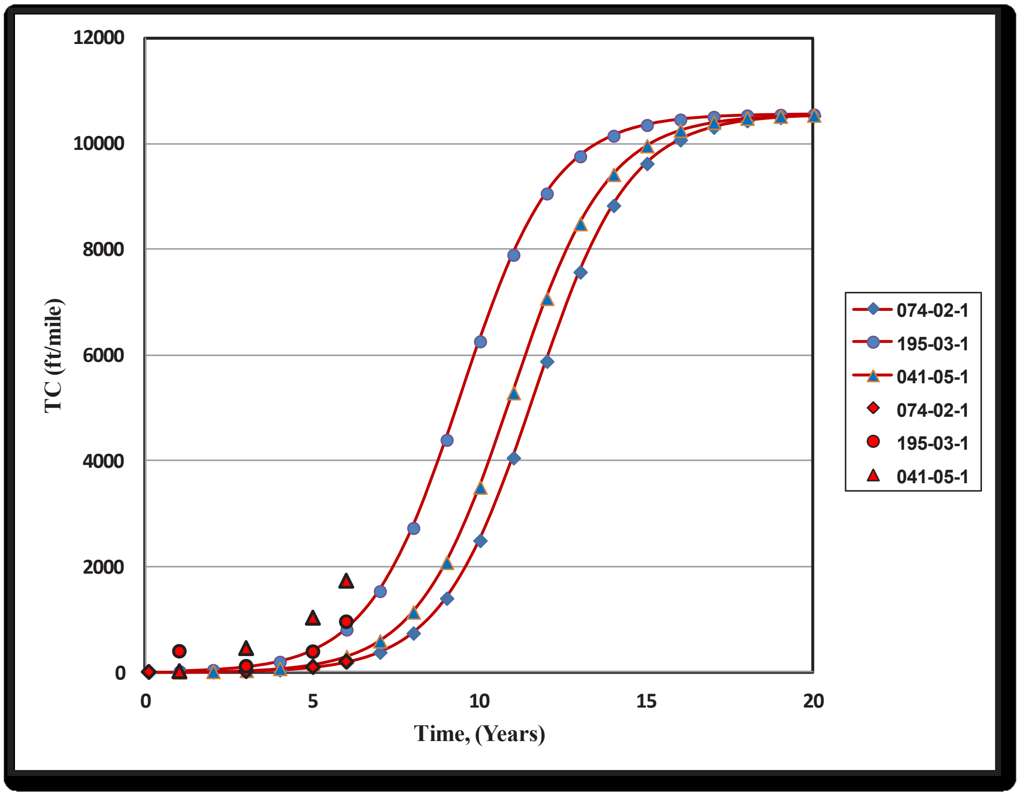

Figure 13: TC Model behavior for Flexible Pavement

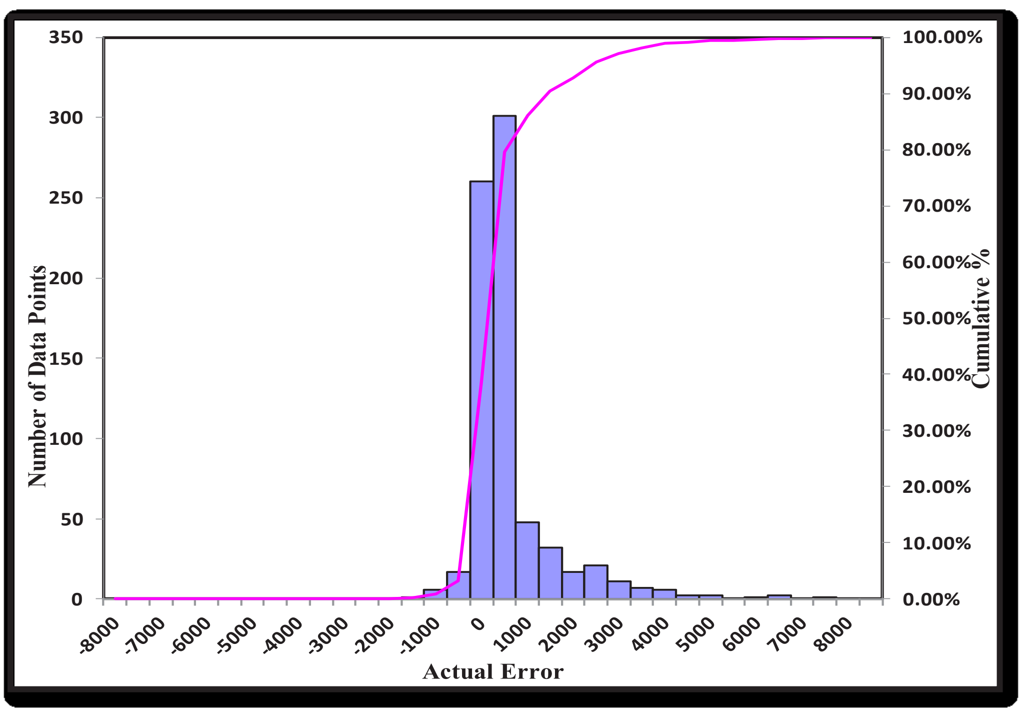

Figure 14: Actual error distribution of transverse crack using regression model

4.2.3 Longitudinal Cracking Model

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:

$$\ln\left(\frac{LC+1}{Max-(LC+1)}\right) = a_o + a_1 * \frac{\ln(CESAL)}{T_H} + a_2 * \left(\frac{1}{Fn}\right) + a_3 * CLTI + a_4 * CTI \qquad (13)$$

Where, LC = transverse cracking (ft/mile), Max = 10560 ft/mile, CESAL = cumulative ESAL, T_H = thickness of HMA overlay (in), Fn = functional classification, CLTI= cumulative Low Temperature Index (°F-days), CTI= cumulative Temperature Index (°F-days). The results of statistical analysis are shown in Table 3.

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

$$LC = \frac{10560}{1 + \exp^{-\left(-7.893 + 0.1240 * \frac{\ln(CESAL)}{TH} - 3.373 * \left(\frac{1}{Fn}\right) + 0.005009 * CLTI + 0.0003336 * CTI\right)}} - 1 \qquad (14)$$

The predicted versus the measured ln((LC+1)/(Max-(LC+1)) values for overlay treatment on Flexible Pavement is shown in Figure 15. 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 16 depicts the predicted LC for three different projects when plotted against time. Figure 17 shows actual error distribution of longitudinal crack and it shows random trend, which is necessary for a good model.

Table 3: 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			7.87×10^{-84}	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-7.893	0.2333	-33.83	4.89×10^{-150}
a_1	0.1240	0.06122	2.03	4.32×10^{-2}
a_2	-3.373	0.5326	-6.33	4.26×10^{-10}
a_3	0.005009	0.0009406	5.32	1.36×10^{-7}
a_4	0.0003336	0.00002023	16.49	6.38×10^{-52}

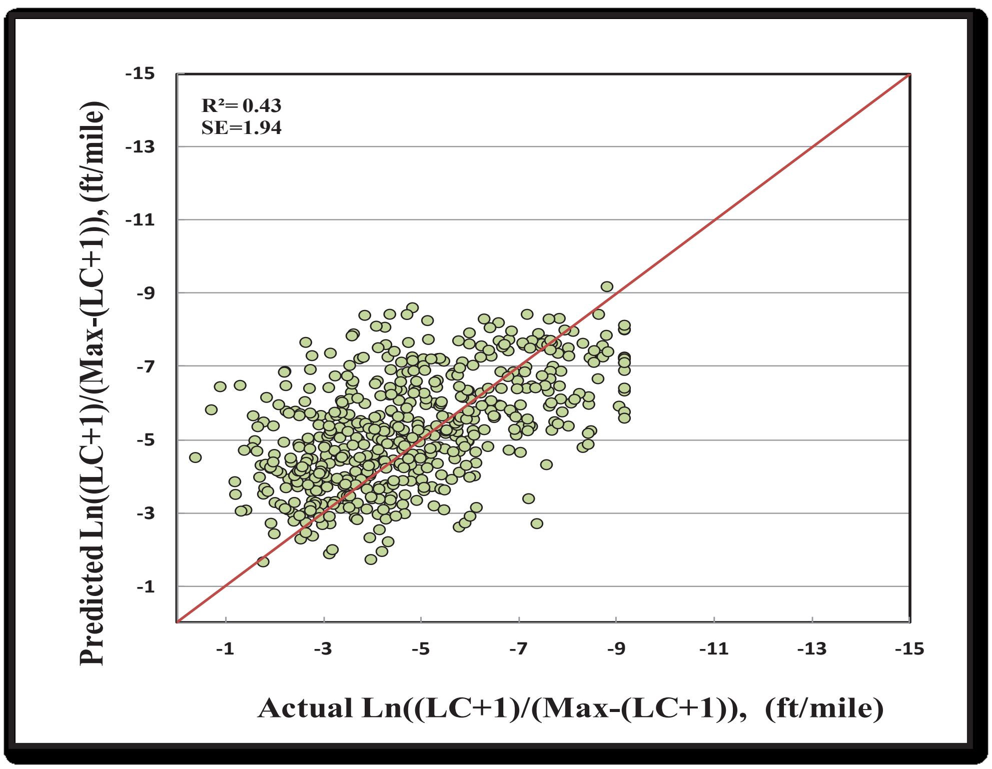

Figure 15: Predicted versus actual Ln((LC+1)/(Max-(LC+1)) for Flexible Pavement

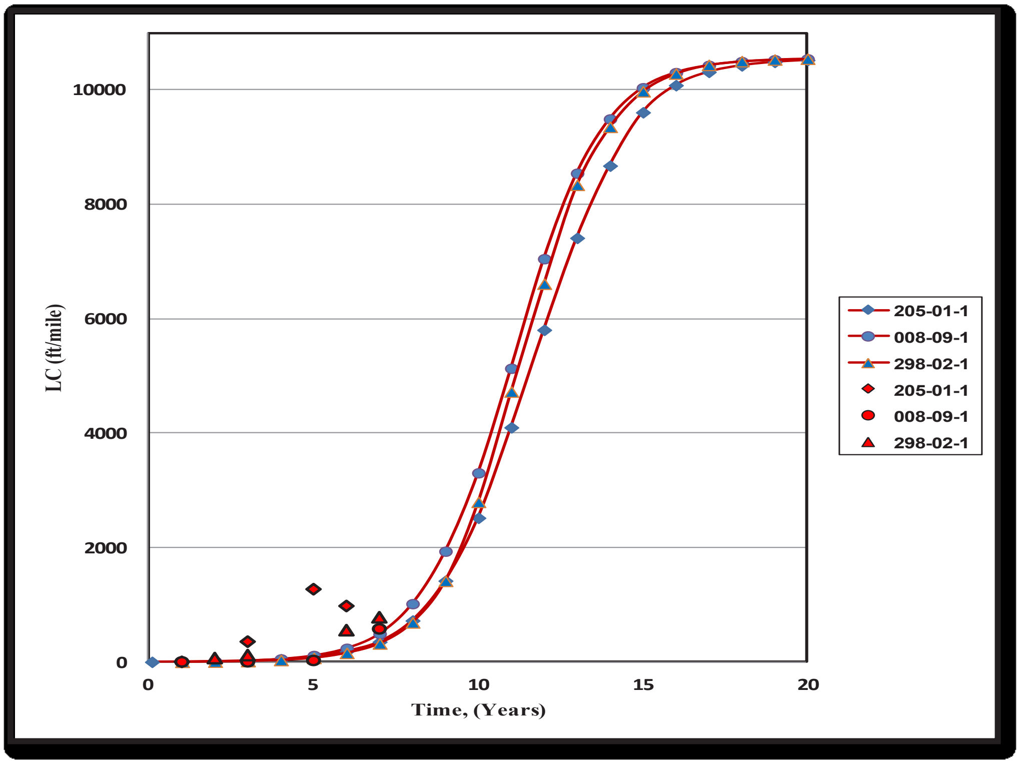

Figure 16: LC Model behavior for Flexible Pavement

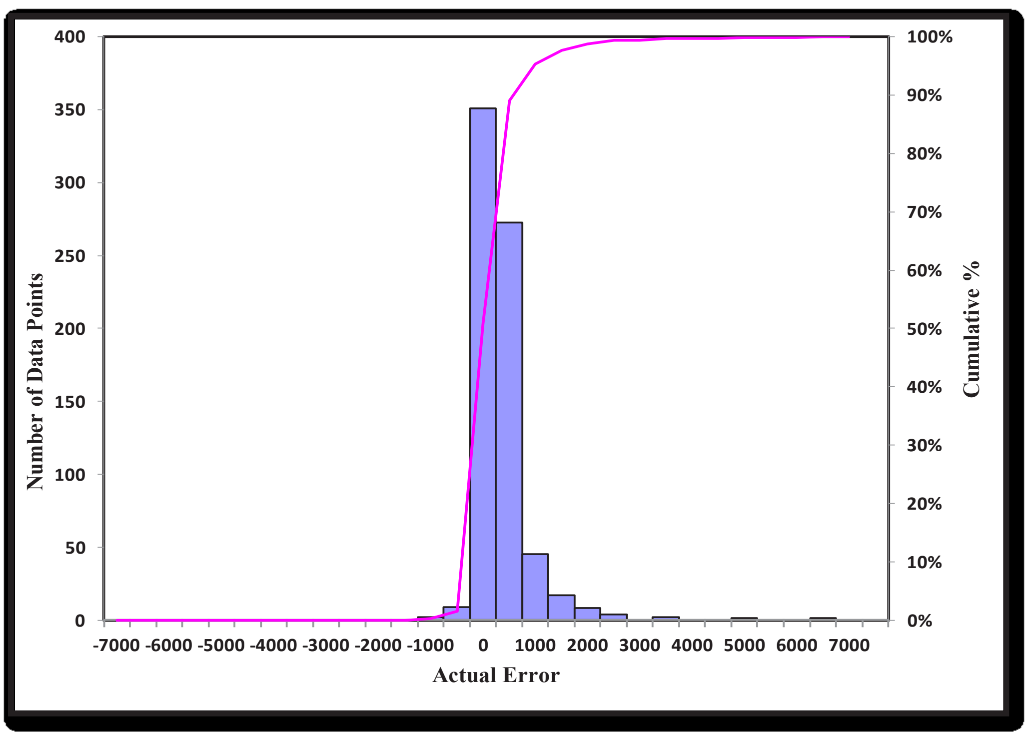

Figure 17: Actual error distribution of longitudinal crack using regression model

4.2.4 Fatigue Cracking Model

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:

$$\ln\left(\frac{FC+1}{Max-(FC+1)}\right)=a_o+a_1*\frac{\ln(CESAL)}{T_H}+a_2*\left(\frac{1}{Fn}\right)+a_3*CLTI+a_4*CTI \quad (15)$$

Where, FC = fatigue cracking (ft²/lane-mile), Max = 31680 ft^2/mile, CESAL = cumulative ESAL, T_H = thickness of HMA overlay (in), Fn = functional classification, CTI = cumulative Temperature Index (°F-days), CLTI= cumulative Low Temperature Index (°F-days). The results of statistical analysis are shown in Table 4.

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

$$FC=\frac{31680}{1+\exp^{-\left(-7.57+0.3545*\frac{\ln(CESAL)}{TH}-6.451*\left(\frac{1}{Fn}\right)+0.004581*CLTI+0.0003626*CTI\right)}}-1 \quad (16)$$

Figure 18 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 models is able to predict the fatigue cracking reasonably well. Also, from the data in Table 4, it is clear that all the variables are statistically significant with p-value ≤0.05. Figure 19 depicts the predicted FC for three different projects when plotted against time. Figure 20 shows actual error distribution of fatigue crack and it shows random trend which is necessary for a good model.

Table 4: 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	$8.30x10^{-103}$
a_1	0.3545	0.07830	4.53	$7.12x10^{-6}$
a_2	-6.451	0.6910	-9.34	$1.66x10^{-19}$
a_3	0.004581	0.001145	4.00	$7.02x10^{-5}$
a_4	0.0003626	0.00002438	14.87	$3.99x10^{-43}$

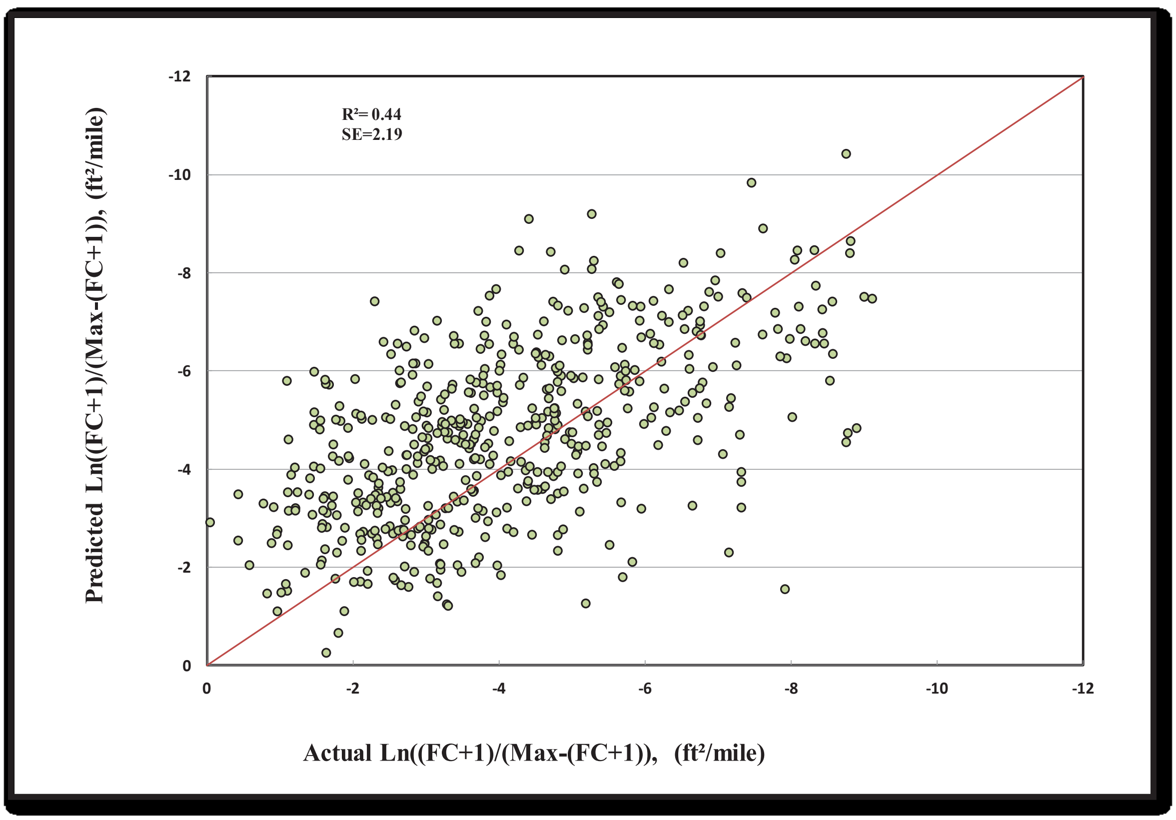

Figure 18: Predicted versus Actual Ln((FC+1)/(Max-(FC+1)) for Flexible Pavement

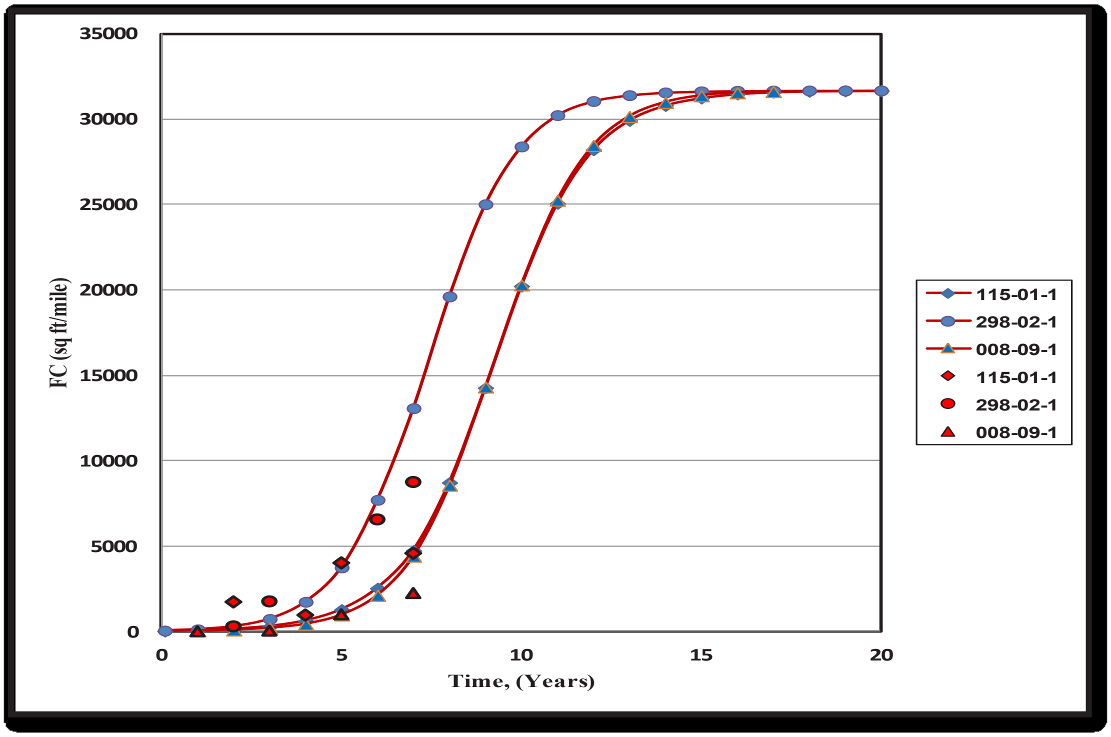

Figure 19: FC Model behavior for Flexible Pavement

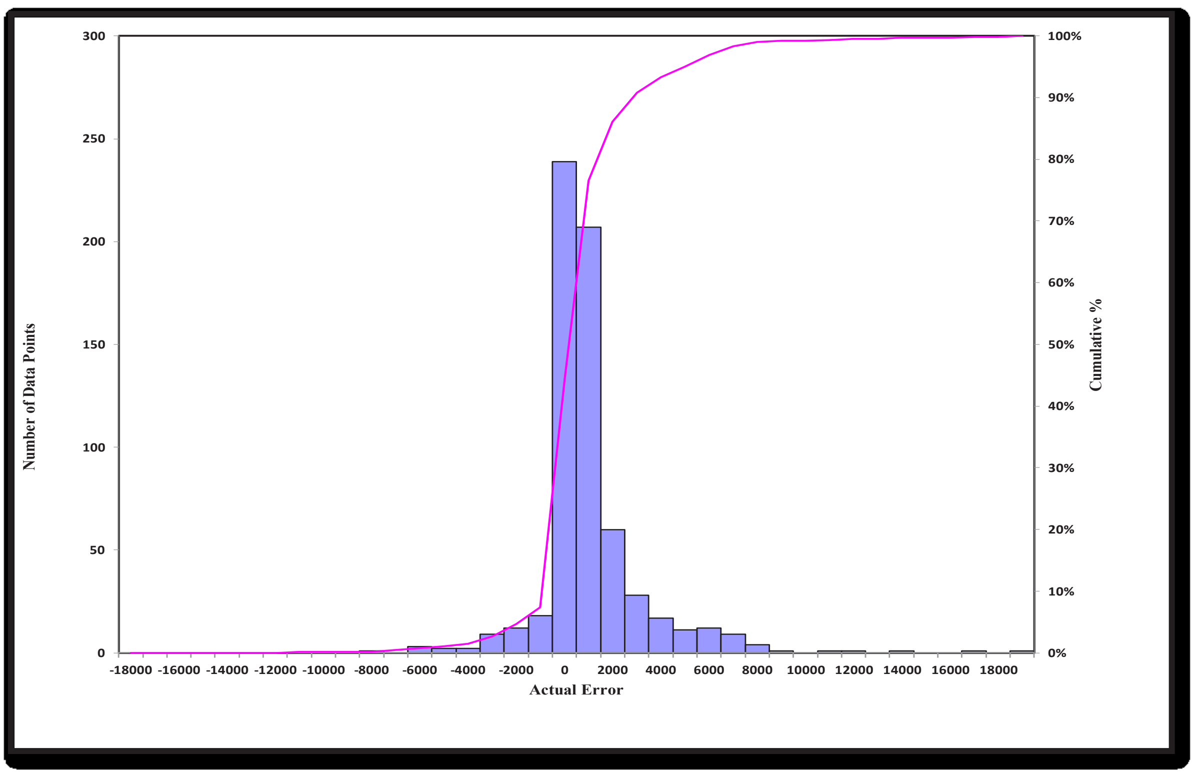

Figure 20: Actual error distribution of FC using regression model

4.2.5 Rut Model

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 model for rutting were based on functional classification. For functional classification: 1, 2, and 3:

$$\ln(Rut) = a_0 + a_1 * \frac{Fn}{T_{HMA}} + a_2 * \ln(t) + a_3 * \ln(CESAL) \quad (17)$$

Where, Rut = average rut depth per lane (in), CESAL = cumulative ESAL, T_{HMA} = thickness of HMA overlay (in), Fn = functional classification, t = age of treatment (year). The results of statistical analysis are shown in Table 5.

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

$$Rut = \exp\left(-3.851 + 0.4114 * \frac{Fn}{T_{HMA}} + 0.7259 * \ln(t) + 0.0409 * \ln(CESAL)\right) \quad (18)$$

For functional classification: 4, 5, and 9:

$$\ln(Rut) = b_0 + b_1 * \frac{Fn}{T_{HMA}} + b_2 * \ln(t) + b_3 * \ln(CESAL) \quad (19)$$

The results of statistical analysis are shown in Table 6. After the regression, the final form of the rutting was found to be:

$$Rut = \exp\left(-4.135 + 0.1331 * \frac{Fn}{T_{HMA}} + 0.6017 * \ln(t) + 0.07061 * \ln(CESAL)\right) \quad (20)$$

Figure 21 shows the predicted versus the measured ln(Rut) values for overlay treatment on Flexible Pavement for all functional classifications by combining both equations. Figure

22 shows rut model behavior when plotted against actual values. Figure 23 shows actual error distribution of rut and it shows random trend which is necessary for a good model. Also, from the data in Table 5 and Table 6 it is clear that all the variables are statistically significant with p-value ≤0.05.

Table 5: 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			$1.96x10^{-65}$	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-3.851	0.4604	-8.36	$1.95x10^{-14}$
a_1	0.4114	0.1334	3.08	$2.37x10^{-3}$
a_2	0.7259	0.04487	16.18	$1.91x10^{-36}$
a_3	0.04090	0.03541	1.16	0.0250

Table 6: 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			5.53×10^{-201}	
Coefficients	Value	Standard Error	t-stats	p-values
b_o	-4.135	0.1862	-22.20	1.96×10^{-80}
b_1	0.1331	0.03635	3.66	2.72×10^{-4}
b_2	0.6017	0.02079	28.94	2.04×10^{-116}
b_3	0.07061	0.01558	4.53	7.05×10^{-6}

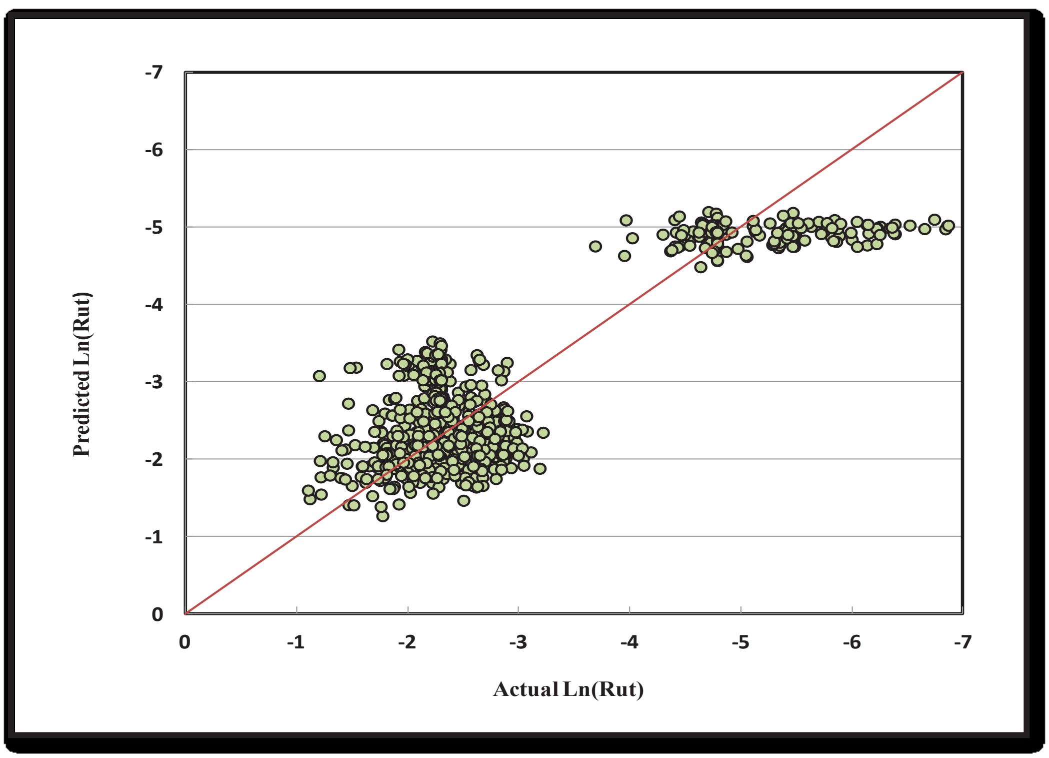

Figure 21: Predicted versus actual Ln(Rut) for Flexible Pavement for all functional classification

Figure 22: Rut Model behavior against measured Rut values for Flexible Pavement

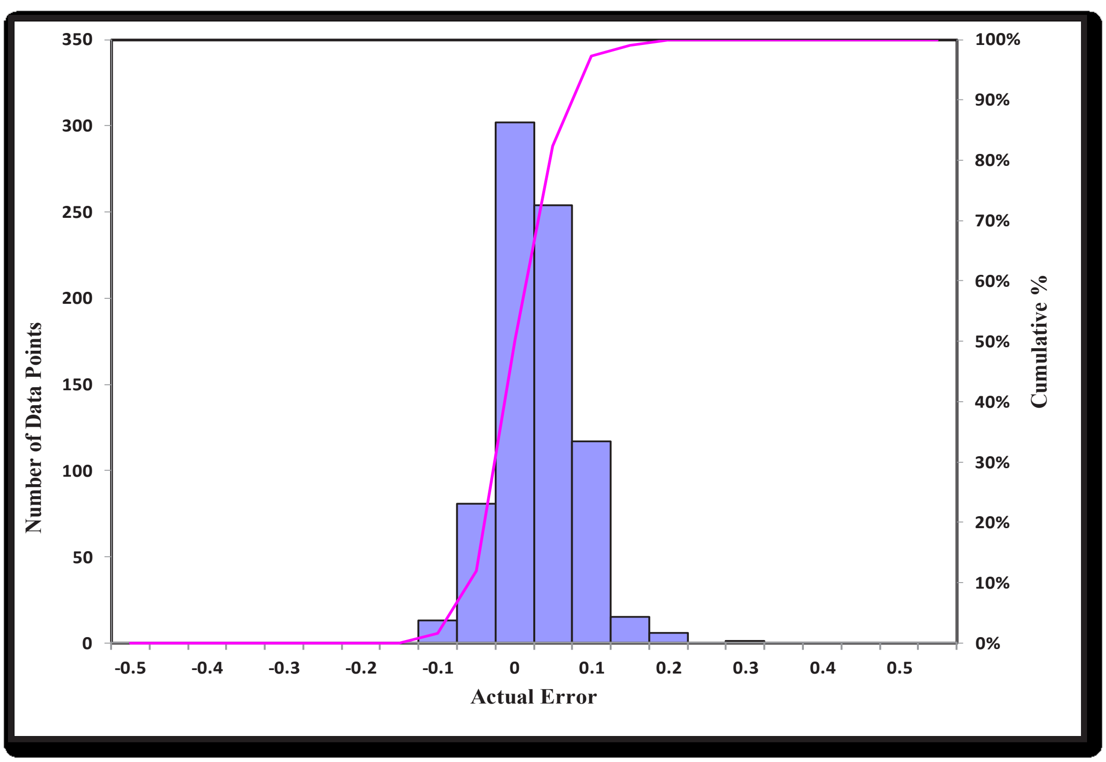

Figure 23: Actual error distribution of rut using regression model

4.3 Flexible Pavement with Chip Seal Treatment

Similar to the above mentioned approach for Flexible Pavement, all other distress models for other pavements and treatments are done. Only the equations will be presented below and the statistical table and figures relating the validity of the model will be provided in Appendix.

4.3.1 International Roughness Index Model

$$IRI = \exp\left(1.045 + 0.8015 * \ln(IRIp) - 0.1937 * \frac{Ap}{Fn} + 0.002740 * \ln(CESAL) * t\right) \quad (21)$$

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

4.3.2 Transverse Cracking Model

$$TC = \frac{10560}{1 + \exp^{-\left(-8.836 + 0.1390 * \ln(CESAL) + 0.0002208 * CTI + 0.5514 * \ln(Crackp+1) - 3.709 * \frac{Ap}{Fn}\right)}} - 1 \quad (22)$$

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

4.3.3 Longitudinal Cracking Model

$$LC = \frac{10560}{1 + \exp^{-\left(-8.372 + 0.2543 * \left(\frac{\ln(CESAL)}{Ap.Fn}\right) + 0.3468 * \ln(Crackp+1) + 0.0002568 * CTI\right)}} - 1 \quad (23)$$

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

4.3.4 Fatigue Cracking Model

$$FC = \frac{31680}{1 + \exp^{-\left(-6.295 + 0.3750 * \left(\frac{\ln(CESAL)}{Ap.Fn}\right) + 0.0002643 * CTI\right)}} - 1 \qquad (24)$$

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

4.3.5 Rut Model

$$Rut = \exp\left(-0.9981 + 0.007529 * \frac{\ln(CESAL)}{Fn} * t + 0.4620 * \ln(Rut_P) + 0.06328 * Ap\right) \qquad (25)$$

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

4.4 Flexible Pavement with Micro surfacing Treatment

4.4.1 International Roughness Index Model

$$IRI = \exp(1.252 + 0.001121 * \ln(CESAL) * Fn * t + 0.6281 * \ln(IRI_P) + 0.2062 * Ap) \qquad (26)$$

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

4.4.2 Transverse Cracking Model

$$TC = \frac{10560}{1 + \exp^{-\left(-10.86 + 0.04584 * \ln(CESAL) * t + 0.7637 * \ln(Crackp + 1) + 3.0311 * \frac{Ap}{Fn}\right)}} - 1 \qquad (27)$$

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

4.4.3 Longitudinal Cracking Model

$$LC = \frac{10560}{1 + \exp^{-\left(-8.372 + 0.2543 * \left(\frac{\ln(CESAL)}{Ap.Fn}\right) + 0.3468 * \ln(Crackp + 1) + 0.0002568 * CTI\right)}} - 1 \qquad (28)$$

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

4.4.4 Fatigue Cracking Model

$$FC = \frac{31680}{1 + \exp^{-\left(-8.839 + 1.384 * \frac{\ln(CESAL)}{Ap.Fn} + 0.03989 * CLTI\right)}} - 1 \qquad (29)$$

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

4.4.5 Rut Model

$$Rut = \exp(-1.7954 + 0.3205 * \ln(IRIp) + 0.01257 * \ln(CESAL) * Ap * \ln(t) + 0.03273 * Fn) \qquad (30)$$

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

4.5 Flexible Pavement with Replacement:

4.5.1 International Roughness Index Model

$$IRI = \exp\left(4.9063 + 0.01145 * \frac{\ln(\mathrm{CESAL}) * t}{T_H} - 0.02843 * T_B - \frac{0.8824}{Fn}\right) \qquad (31)$$

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

where,

T_B= Non-Asphalt Thickness of Base ; T_H=Thickness of Asphalt Layer(Including Asphalt thickness of Base)

4.5.2 Transverse Cracking Model

$$TC = \frac{10560}{1 + \exp^{-\left(-10.04 + 0.00001836 * \ln(CESAL) * CTI + 2.665 * \frac{Fn * T_H}{(T_H + T_B)}\right)}} - 1 \qquad (32)$$

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

4.5.3 Longitudinal Cracking Model

$$LC = \frac{10560}{1 + \exp^{-\left(-9.347 + 0.00001419 * \ln(CESAL) * CTI + 2.037 * \frac{Fn * T_H}{(T_H + T_B)}\right)}} - 1 \qquad (33)$$

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

4.5.4 Fatigue Cracking Model

$$FC = \frac{31680}{1 + \exp^{-\left(-4.25 + 0.943 * \ln(CESAL) + 0.00003172 * CPI - 0.3644 * T_H - 0.3447 * T_B - \frac{24.17}{Fn}\right)}} - 1 \qquad (34)$$

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

4.5.5 Rut Model

$$Rut = \exp\left(-2.565 + 0.06399 * \ln(CESAL) * \ln(t) - 0.07904 * \frac{T_H}{Fn} - 0.05056 * T_B\right) \qquad (35)$$

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

4.6 Determining Treatment Life using these models:

These Models can be used to determine Treatment Life of pavement for different treatment types. An Example of IRI and FC prediction by the models is shown in Figure 24 and Figure 25 for the roadway section 084-01:

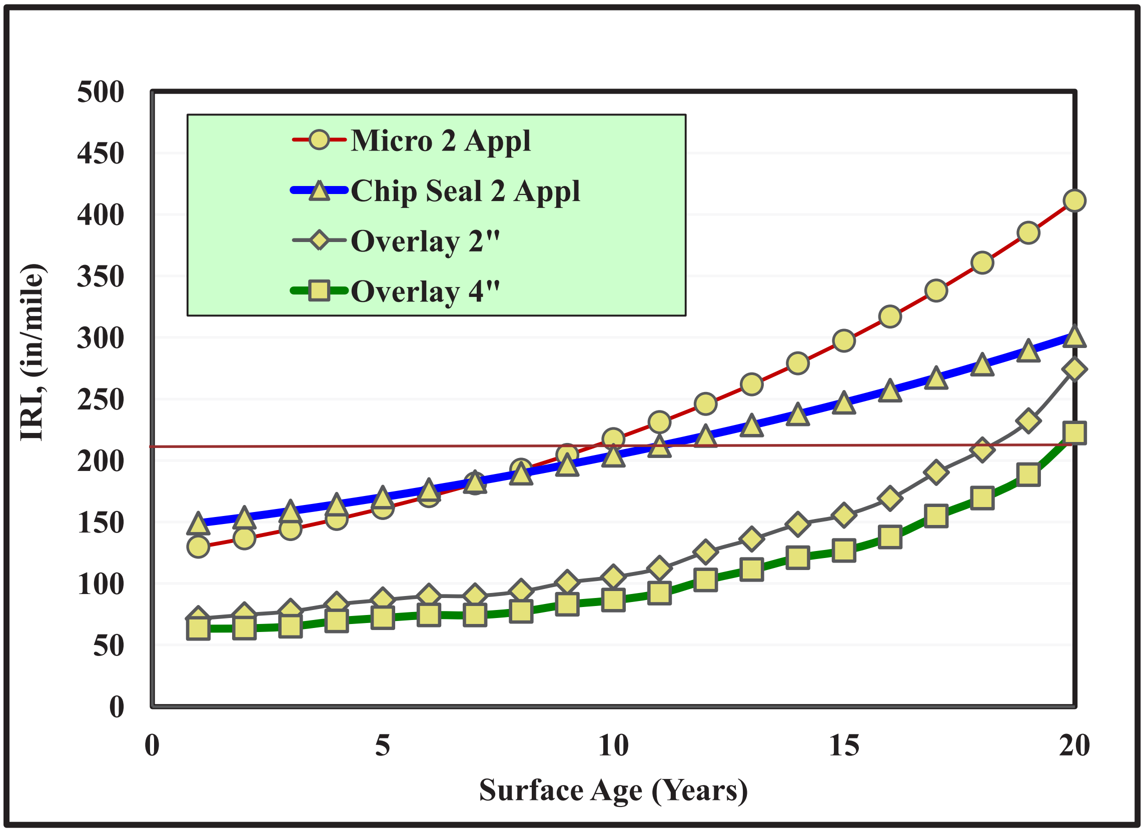

Figure 24: IRI Prediction for Different Treatment types

Figure 24 shows, for Control Section 084-01-1, if Micro surfacing 2 application is applied, the pavement will have 10 years of life. For Chip Seal 2 application, the life will be slightly less, 9 years. Overlay 2 inch and Overlay 4 inch will give 18 and 20 years of life. (If only IRI is considered as only Distress).

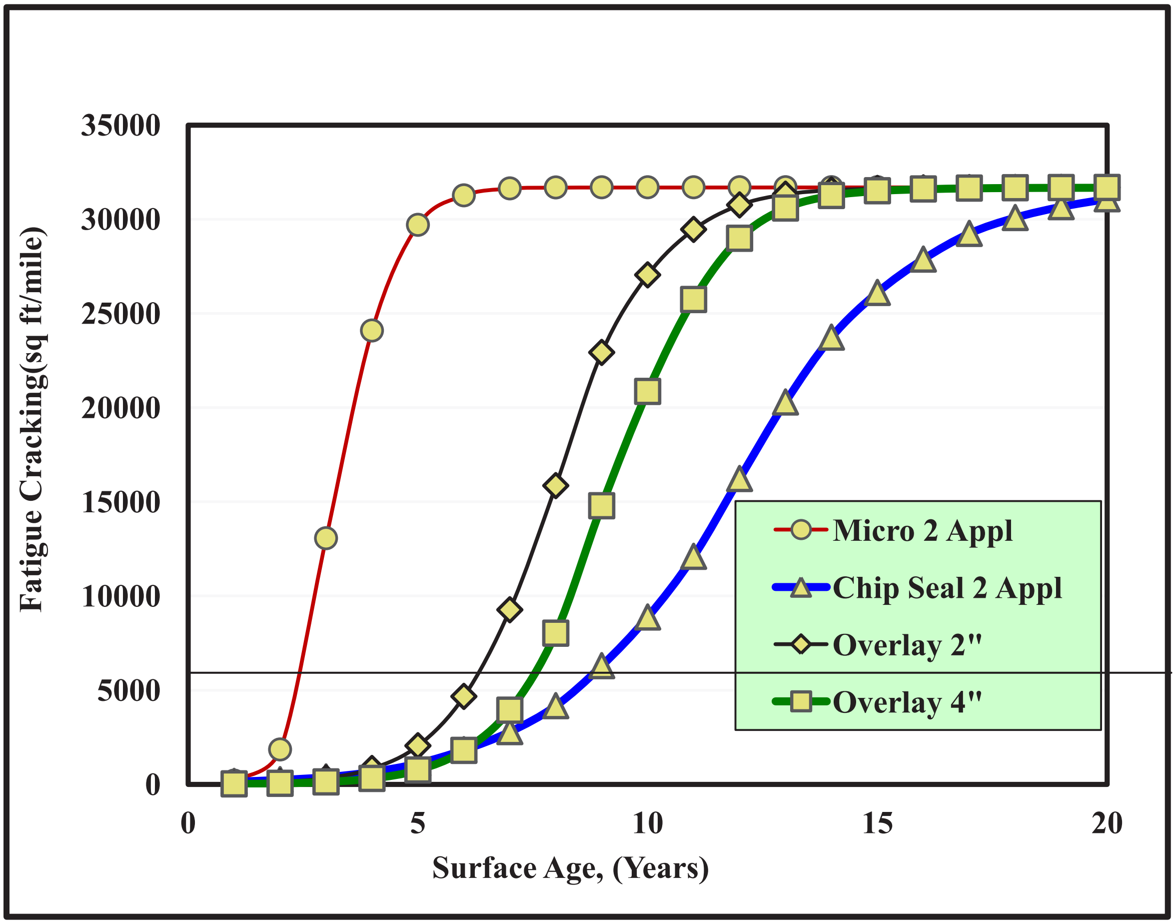

Figure 25: FC Prediction for Different Treatment types

Similarly, Figure 25 shows, for Control Section 084-01-1, if Micro surfacing 2 application is applied, the pavement will have 2.5 years of life. for Chip Seal 2 application, the life will be 11 years. Overlay 2 inch and Overlay 4 inch will give 7 and 8 years of life. (If only FC is considered as only Distress).

In general, the life of treatment is calculated for all five distresses and the minimum life for a particular distress type is considered as the life of a treatment. It means, these models will help LADOTD to determine specific treatment life regarding each treatment type. If cost of each treatment is known, it will be possible to find most cost-effective treatment for any particular Flexible Pavement.

Building a software are in a process by which the most cost-effective treatment can be selected.

By the end of this research project, this software is supposed to be delivered to LADOTD which will automatically calculate the benefit for each treatment and select the most cost-effective treatment for any particular section.

Chapter 5: Conclusions and Recommendations

The purpose of this study was to develop treatment performance models so that all distress values can be predicted, treatment life can be forecasted and the most cost-effective treatment can be selected. Based on the results and analysis of the study, the following conclusions and recommendations were drawn:

- 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.
- The newly developed temperature and precipitation indices (Temperature Index, Low Temperature Index and Precipitation Index) showed strong statistical significance for predicting pavement distresses. The indices along with other variables were incorporated into the pavement performance prediction models.
- The pavement distress prediction models developed for each treatment (IRI, Crackings and Rut) can predict the actual time series data well. Hence, it is recommended to use these models to predict the distress values and the life of treatment.
- Every two years LADOTD add new time series data to its database. Number of data points for each distress type for each treatment type will increase if those data could be added to the model. Hence, it is recommended to calibrate these models when new data is available.
- Since the thickness data is not reported in the Pavement Management System (PMS) database, significant proportion of research time was spent to retrieve the

thickness data of overlay treatments. Therefore, it is recommended that all the thickness data be reported in the PMS main database.

- It was found that the cost of treatment was not available in the PMS database. Only average cost was presented for each treatment which was non specific of a particular projects. Hence, treatment cost data is suggested to be reported in the PMS main database.
- It is strongly recommended that the newly developed pavement prediction models be used by LADOTD pavement management and pavement preservation group to evaluate the pavement treatment performance and cost-effectiveness of any particular treatment.

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Appendix

Flexible Pavement Chip Seal:

IRI (Chip Seal)

Table 6: 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

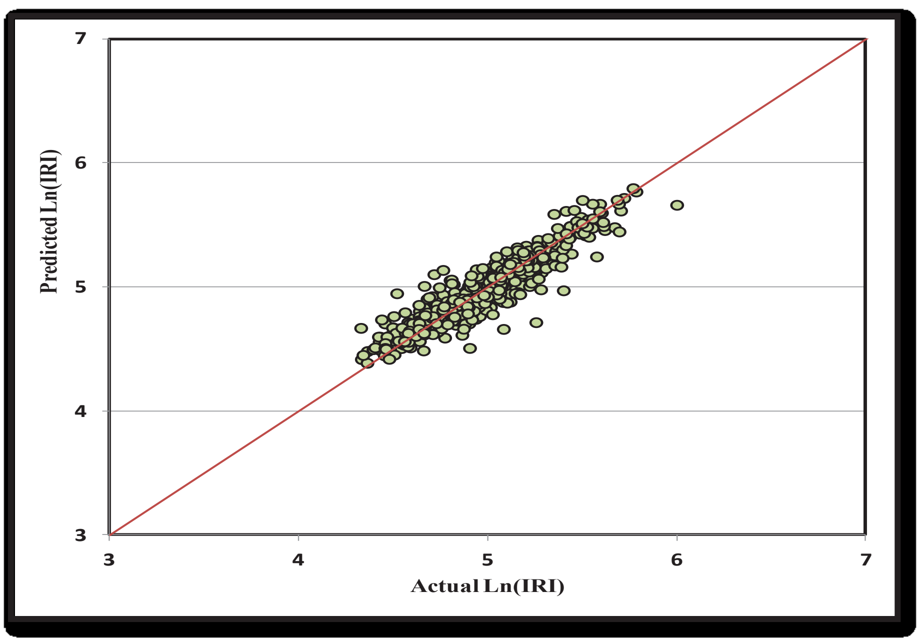

Figure 26: Actual vs Predicted ln(IRI) for Flexible Pavement.

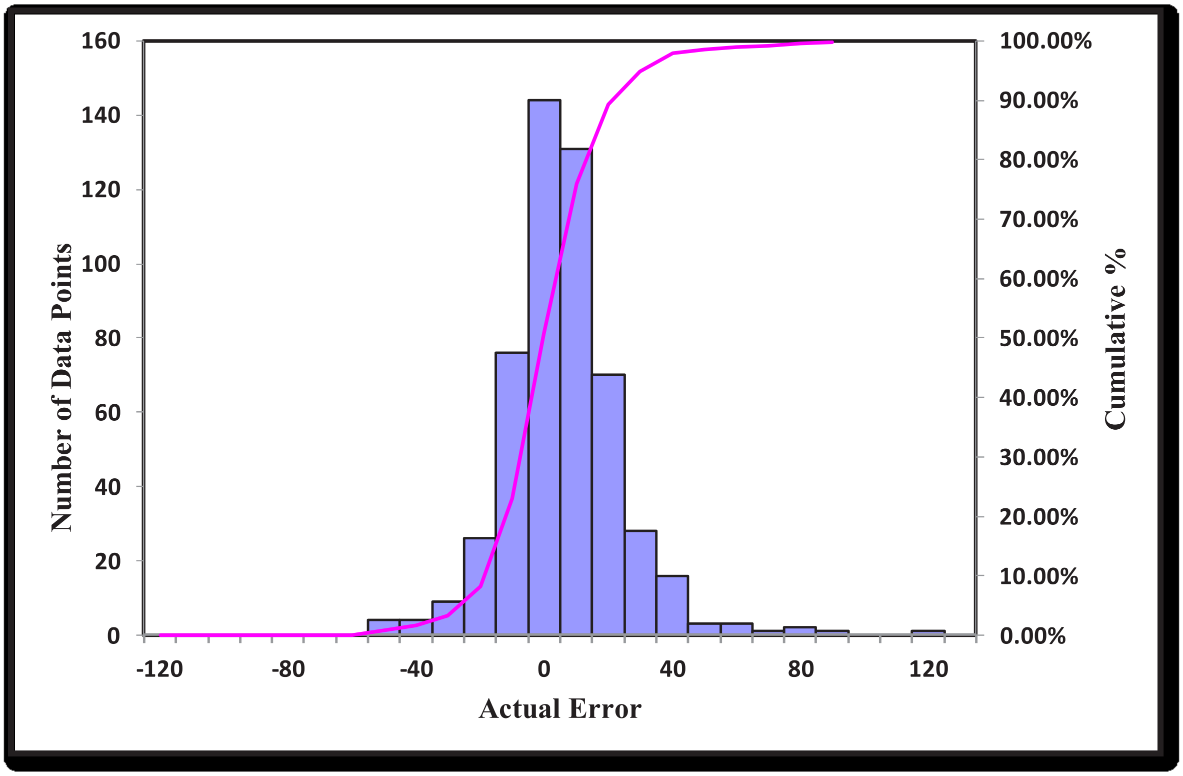

Figure 27: Error Distribution of actual IRI for Flexible Pavement

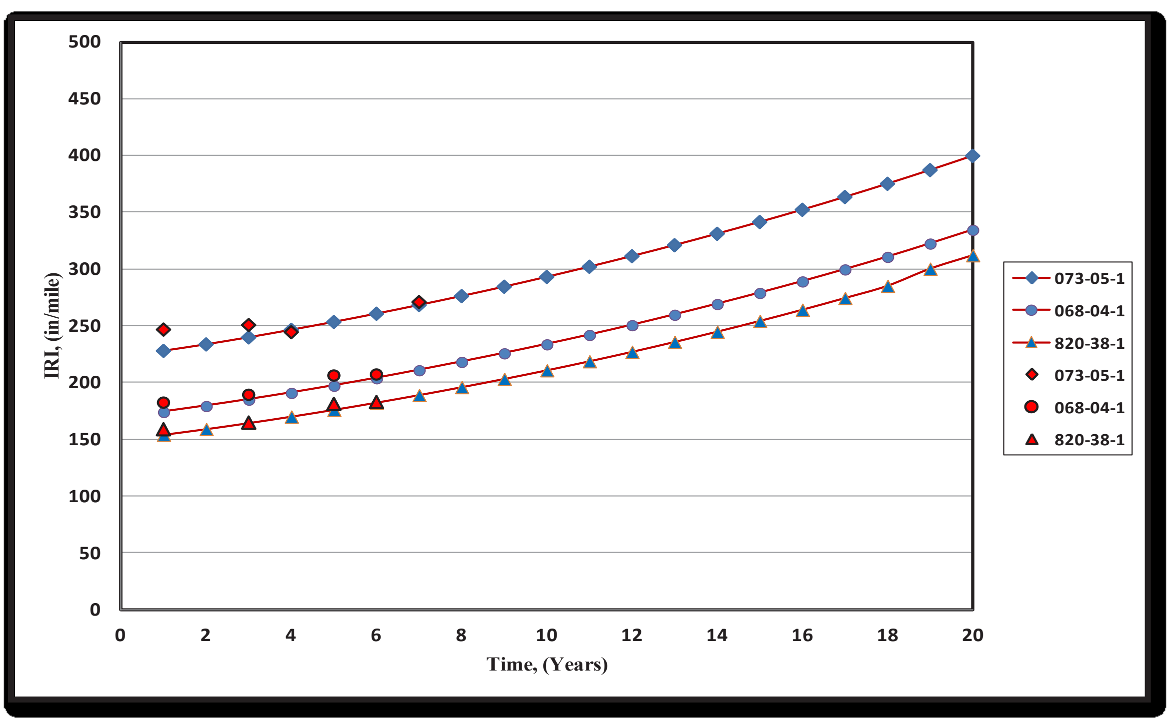

Figure 28: Behavior of IRI for Flexible Pavement

Rut (Chip Seal)

Table 7: 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

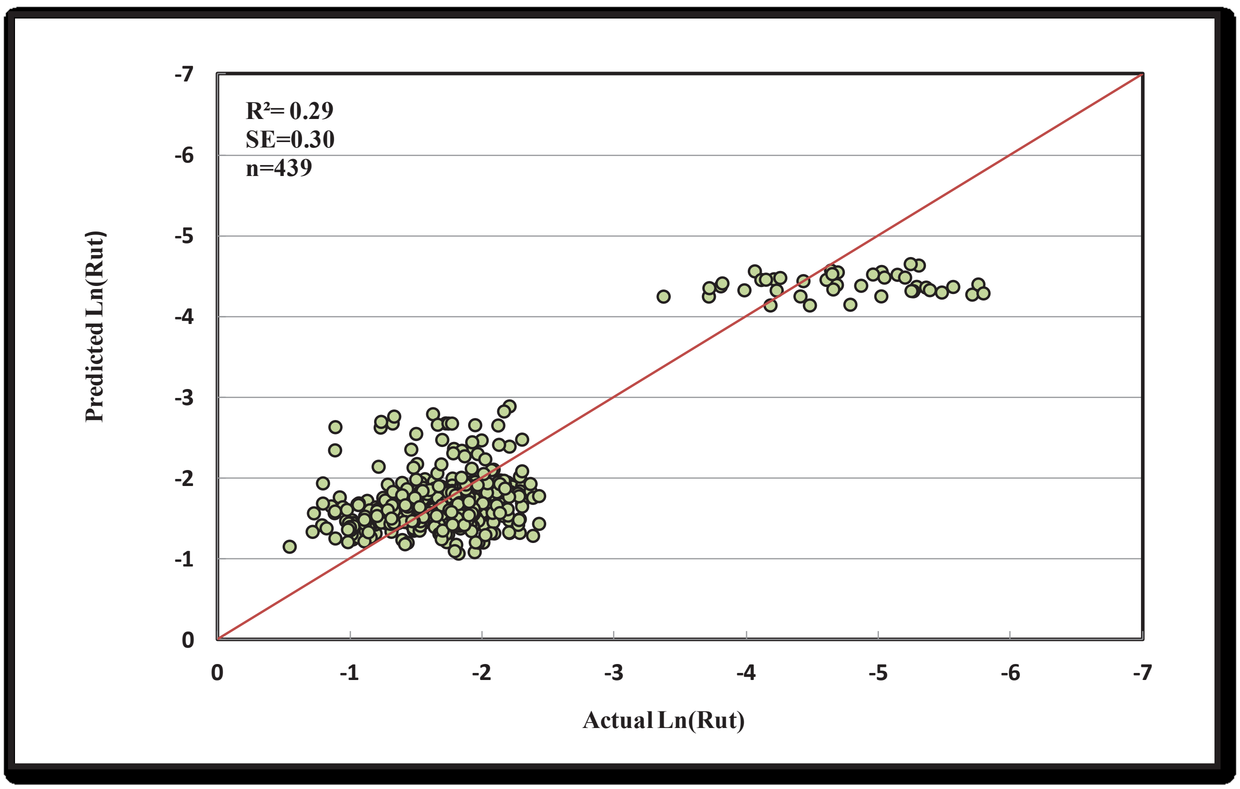

Figure 29: Predicted vs Actual ln(Rut) for Flexible Pavement.

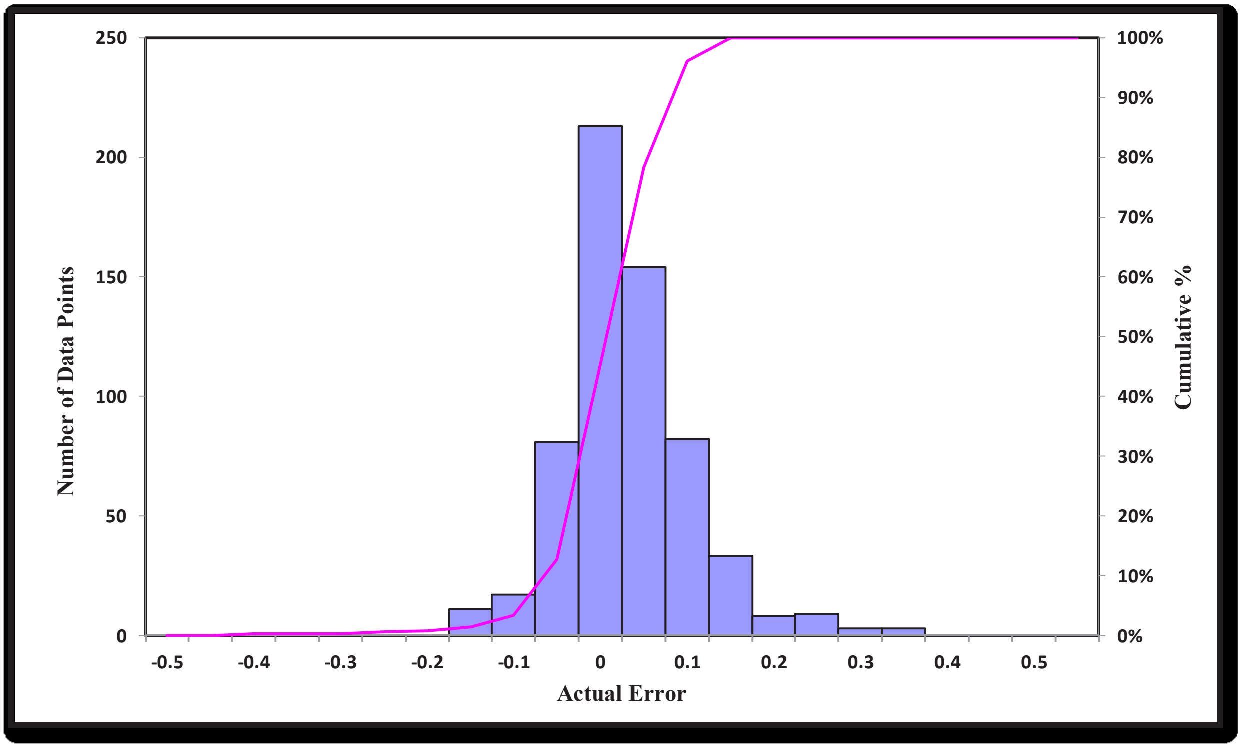

Figure 30: Predicted vs Actual ln(Rut) for Flexible Pavement.

Transverse Crack (Chip Seal)

Table 8: Statistics of the regression analysis of TC model for Flexible Pavement

Regression Statistics				
Multiple R			0.59	
R Square			0.35	
Adjusted R Square			0.34	
Standard Error			1.67	
Observations			531	
F-statistics			70.57	
Significance-F			7.90E-48	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-8.836	0.6441	-13.72	7.93E-37
a_1	0.1390	0.04533	3.07	2.28E-03
a_2	0.0002208	0.00002192	10.07	6.10E-22
a_3	0.5514	0.06766	8.15	2.69E-15
a_4	-3.709	0.7168	-5.17	3.26E-07

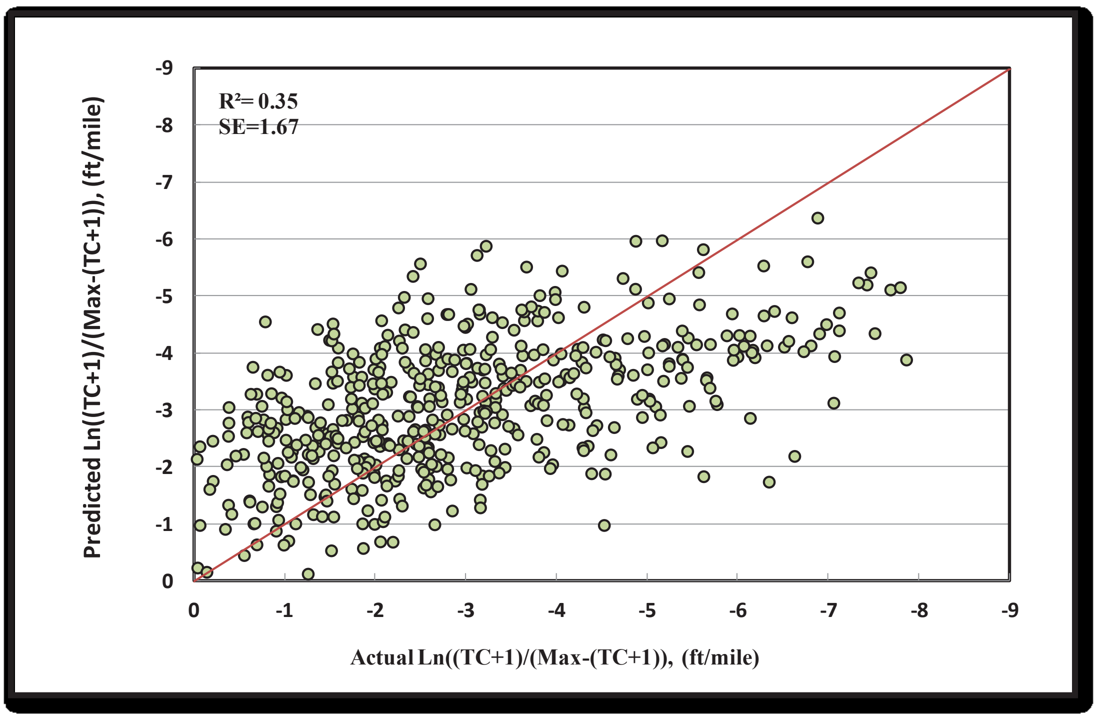

Figure 31: Predicted versus actual Ln((TC+1)/(Max-(TC+1))

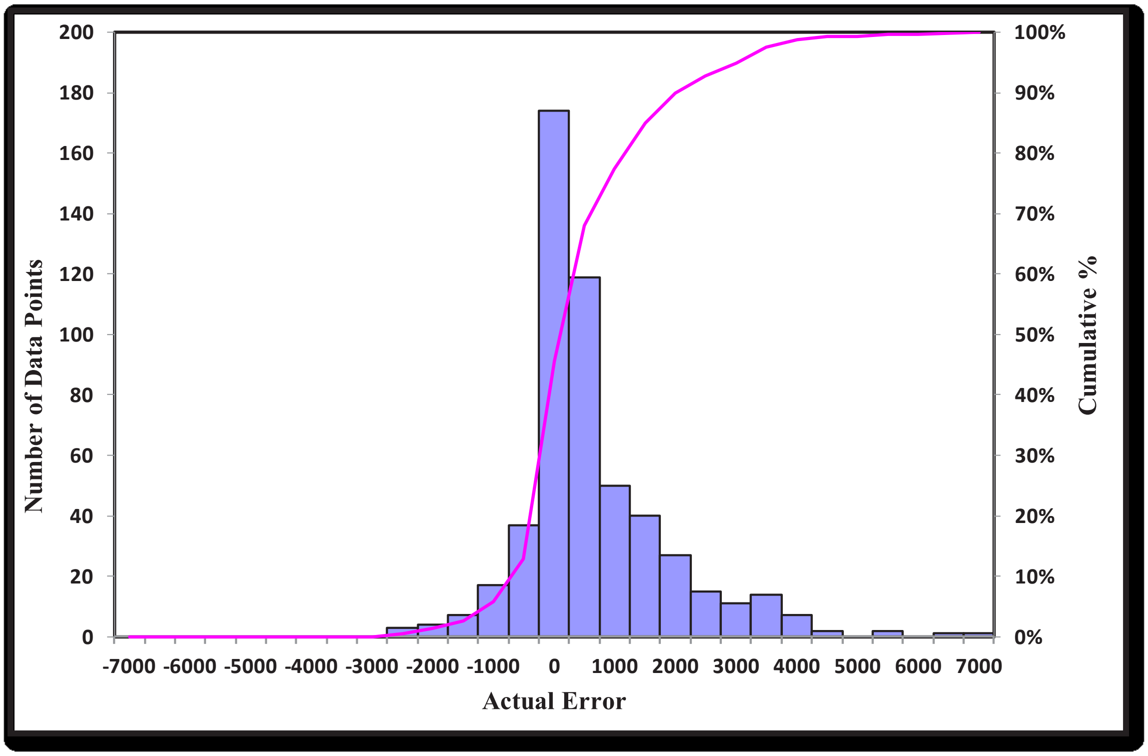

Figure 32: Actual error distribution of TC using regression model

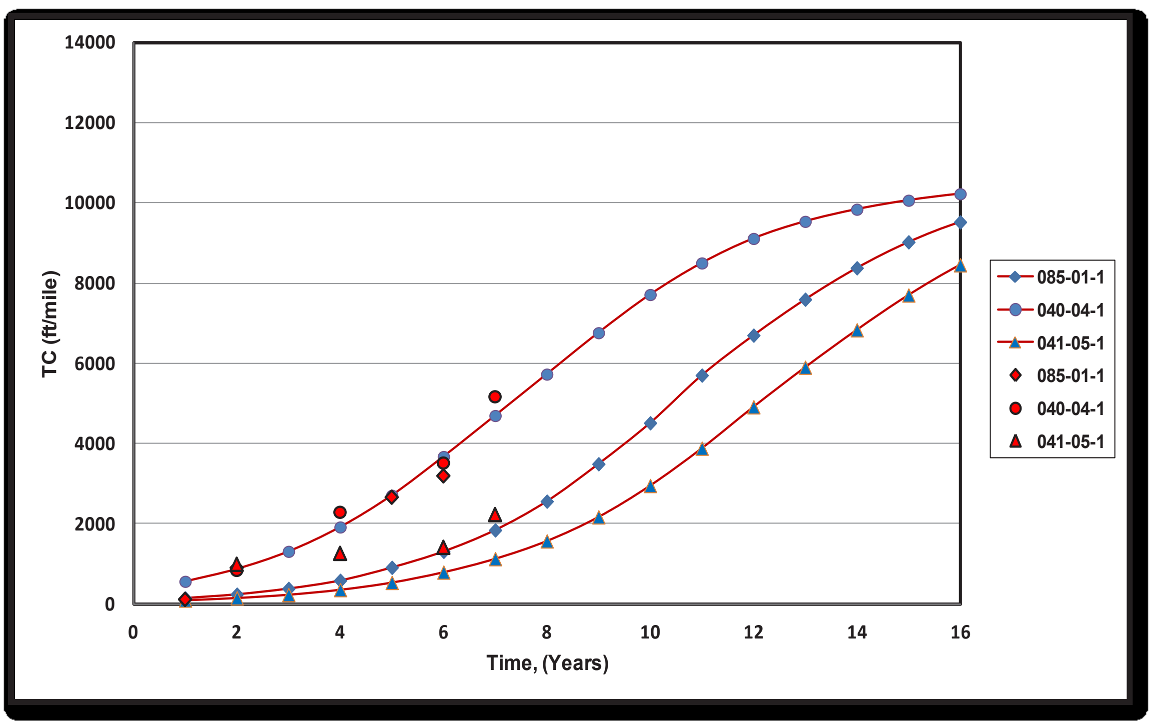

Figure 33: TC Model behavior for Flexible Pavement

Longitudinal Cracking (Chip Seal)

Table 9: 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

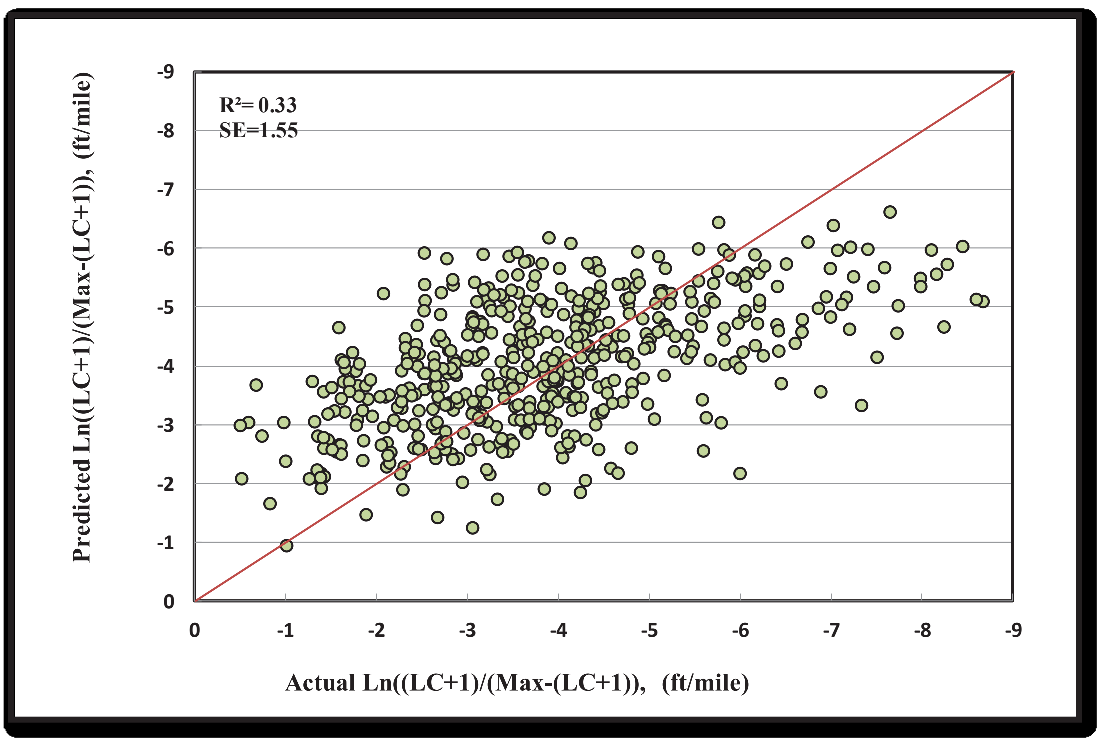

Figure 34: Predicted versus actual Ln((LC+1)/(Max-(LC+1)) for Flexible Pavement

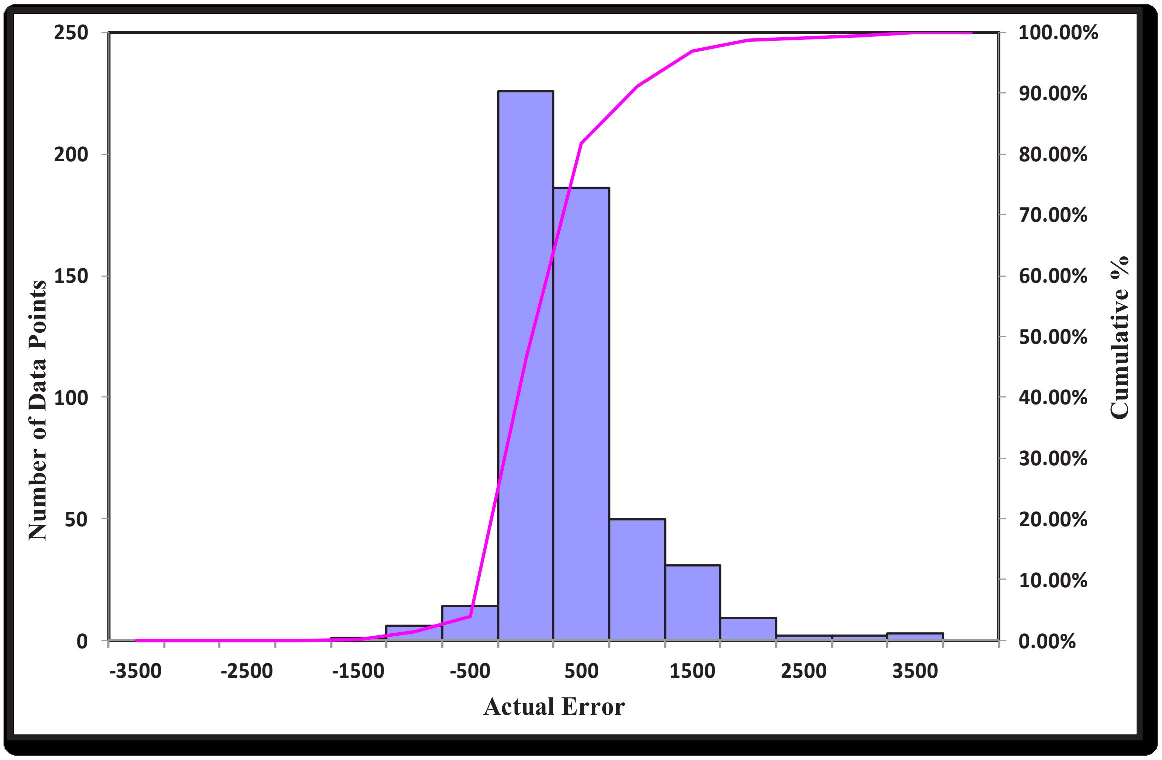

Figure 35: Actual error distribution of longitudinal crack using regression model

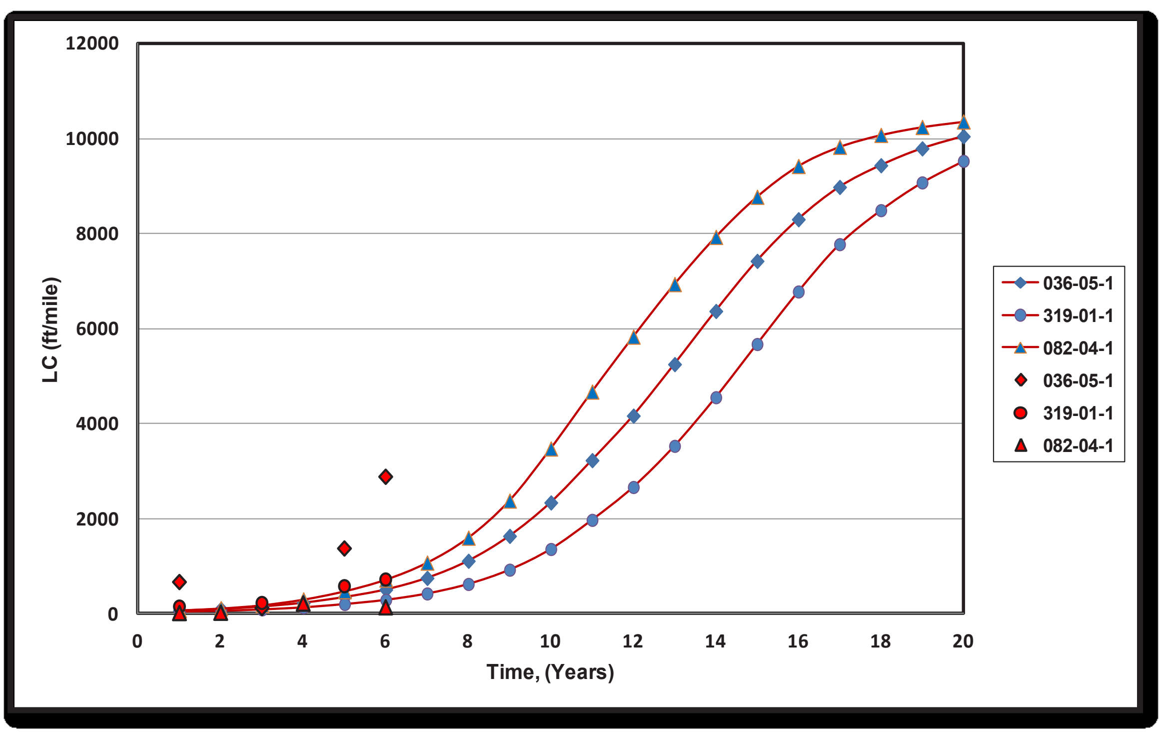

Figure 36: LC Model behavior for Flexible Pavement

Fatigue Cracking (Chip Seal)

Table 10: 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

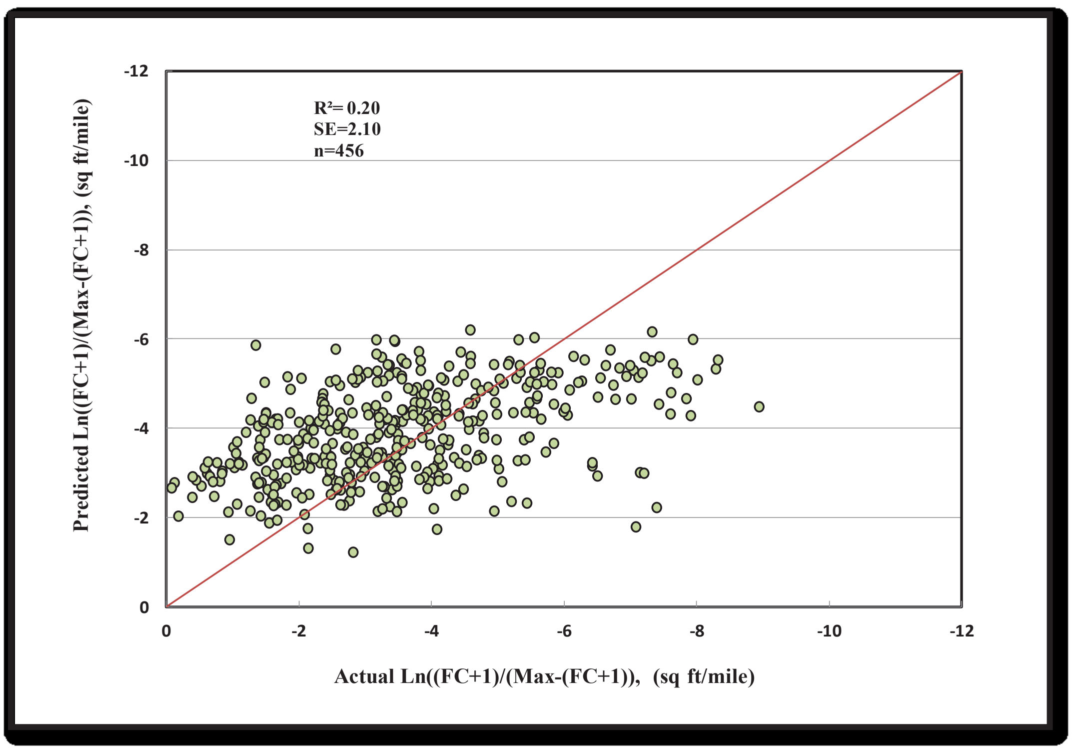

Figure 37: Predicted versus actual Ln((FC+1)/(Max-(FC+1)) for Flexible Pavement

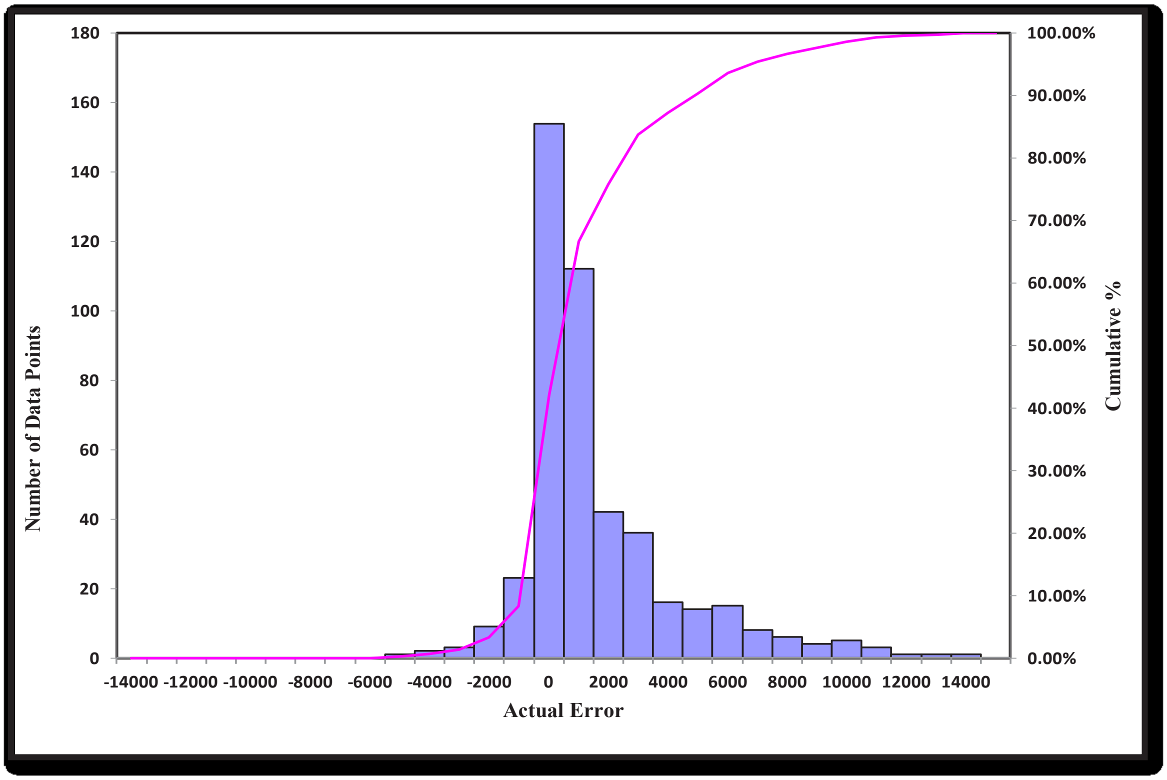

Figure 38: Actual error distribution of rut using regression model

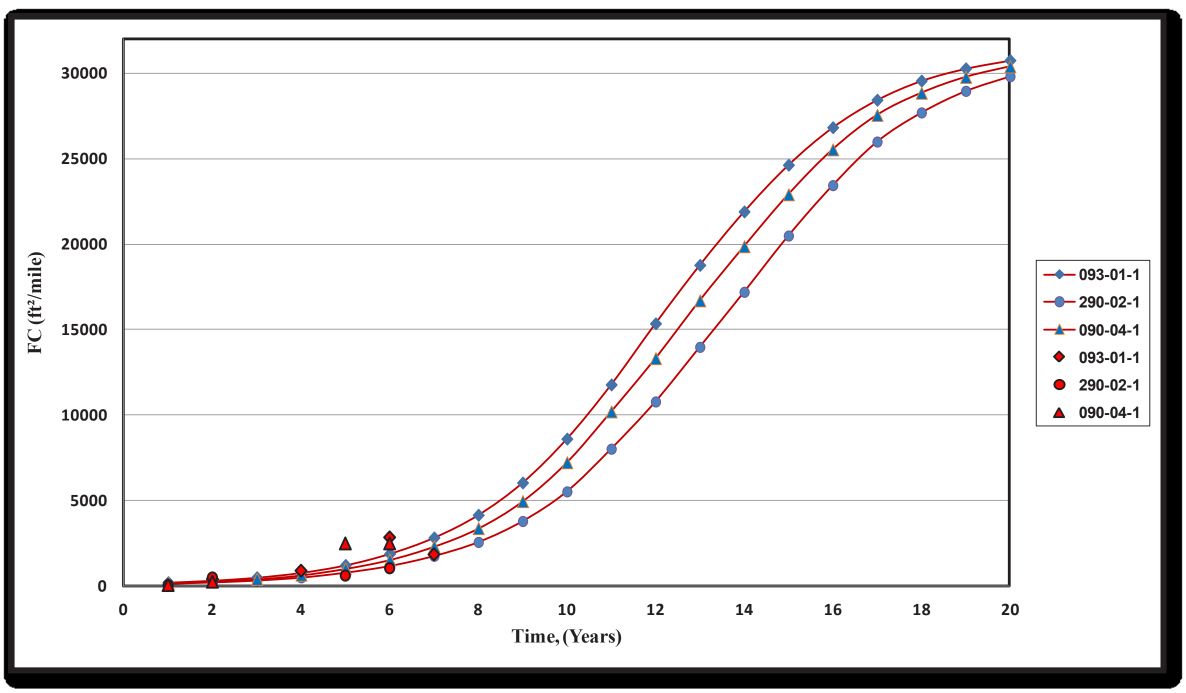

Figure 39: FC Model behavior for Flexible Pavement

Flexible Pavement Micro surfacing:

IRI (Micro surfacing)

Table 11: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 (Micro surfacing)

Table 12: 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 (Micro surfacing)

Table 13: Statistics of the regression analysis of TC model for Flexible Pavement

Regression Statistics				
Multiple R			0.74	
R Square			0.55	
Adjusted R Square			0.51	
Standard Error			2.04	
Observations			34	
F-statistics			12.38	
Significance-F			1.92E-05	
Coefficients	Value	Standard Error	t-stats	p-values
a_o	-10.86	1.213	-8.95	5.62E-10
a_1	0.04584	0.01862	2.46	1.98E-02
a_2	0.7637	0.1702	4.49	9.86E-05
a_3	3.03107	2.855	1.06	2.97E-01

Longitudinal Crack (Micro surfacing)

Table 14: 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 (Micro surfacing)

Table 15: 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:

IRI (Replacement)

Table 16: 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 (Replacement)

Table 17: 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 (Replacement)

Table 18: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 (Replacement)

Table 19: 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 (Replacement)

Table 20: 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

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Thesis Director: Dr. Mohammad Jamal Khattak
Pages in Thesis: 76; Words in Abstract: 276

ABSTRACT

Louisiana has 18,000 miles of roadways that deteriorate over time due to increased traffic loads, environmental factors and aging. The Louisiana Department of Transportation and Development (LADOTD) has been spending significant capital for rehabilitation and maintenance treatment programs for these roadways. These treatments such as Overlay, Chip Seal and Micro surfacing delay the Replacement of the pavement by increasing its life. Performance models for these treatments are necessary to find the most cost-effective treatment and the application time of the treatment for any particular pavement. Till now, a full scale performance assessment for above mentioned treatments and cost-effectiveness analysis are not conducted which would provide LADOTD the advantage of selecting the most cost-effective treatment for Flexible Pavement. The objective of this research is to build performance models for all above mentioned treatments for Flexible Pavement which will facilitate LADOTD to determine the most cost-effective treatment and the application time of the treatment for Flexible Pavement.

Various LADOTD databases were thoroughly searched for time series distress data and historical data of projects. Climatic Indices (Temperature Index, Low Temperature Index and Precipitation Index) are developed. 972 roadway sections are found to have sufficient data to build models for all above mentioned treatment types. Performance models for all five major distress types such as International Roughness Index (IRI), Rut, Fatigue Cracking,

Transverse Cracking and Longitudinal Cracking are developed for the treatments mentioned above in this research. These models are found to be the function of highway functional classification, cumulative ESAL, thickness of the pavement, temperature and precipitation. A software is promised to LADOTD that will evaluate the most cost-effective treatment for any Flexible Pavement section using these performance models.

Biographical Sketch

Mohammad Reza-Ul-Karim Bhuyan, son of Mohammad Habibur Rahman Bhuyan and Hosne Ara Begum, was born on August 19, 1984 in Dhaka, Bangladesh. He passed higher secondary school with a certificate from B.A.F. Shaheen College, Tejgaon in 2001. After that, he obtained his Bachelor of Science in Civil Engineering from Bangladesh University of Engineering and Technology in 2007. In Spring 2011, Bhuyan started his graduate study at the University of Louisiana at Lafayette under the supervision of Dr. Mohammad Jamal Khattak. In Fall 2013, he hopes to achieve his Master of Science in Engineering, Civil Engineering option from UL Lafayette.