TECHNICAL REPORT STANDARD PAGE

f 1. Report No. **FHWA/LA.08/460**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Development of Index Based Pavement Performance Models for Pavement Management System (PMS) of LADOTD**	5. Report Date **March 2009** 6. Performing Organization Code **LTRC Project Number: 04-2P** **State Project Number: 736-99-1342**	
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9. Performing Organization Name and Address **Department of Civil Engineering** **University of Louisiana at Lafayette** **Lafayette, LA 70804**	10. Work Unit No. 11. Contract or Grant No. **LTRC Project No: 04-2P** **State Project No: 736-99-1342**	
12. Sponsoring Agency Name and Address **Louisiana Department of Transportation and Development** **P.O. Box 94245** **Baton Rouge, LA 70804-9245**	13. Type of Report and Period Covered **Final Report** **10/1/2006-03/30/2009** 14. Sponsoring Agency Code	

15. Supplementary Notes
Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

This report focuses on pavement performance and treatment models for Louisiana Department of Transportation and Development (LADOTD) and is in continuation of Louisiana Transportation Research Center (LTRC) Report No. 430 “Development of Uniform Sections for Pavement Inventory.” During the course of the study, a comprehensive evaluation and analysis of the pavement performance prediction and treatment models were conducted using LADOTD pavement distress data and historical information. Statistical analyses were used to generate models for pavement condition prediction and treatment performance evaluation based on the “surface age” or the “age” of pavements. These prediction models were developed for each distress type for four pavement types and four highway system classifications. The developed models provided good predictions and helped determine the remaining service life and pavement network health evaluation. Further research study is required to conduct comprehensive analyses of pavement treatment selection models based on LADOTD distress data and a scheme for the selection of the most cost-effective pavement treatment/preservation action based on the treatment performances and causes of distress. It is believed that findings of this study will enhance LADOTD’s capabilities in predicting pavement performance and monitoring pavement network condition in a most efficient and cost-effective manner.

17. Key Words Pavement Management Systems, Pavement Distress		18. Distribution Statement **Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.**	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 168	22. Price

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Development of Index Based Pavement Performance Models for Pavement Management System (PMS) of LADOTD

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LTRC Project No. 04-2P
State Project No. 736-99-1342

conducted for

Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

March 2009

ABSTRACT

This report focuses on pavement performance and treatment models for Louisiana Department of Transportation and Development (LADOTD) and is in continuation of Louisiana Transportation Research Center (LTRC) Report No. 430 "Development of Uniform Sections for Pavement Inventory." During the course of the study, a comprehensive evaluation and analysis of the pavement performance prediction and treatment models were conducted using LADOTD pavement distress data and historical information. Statistical analyses were used to generate models for pavement condition prediction and treatment performance evaluation based on the "surface age" or the "age" of pavements. These prediction models were developed for each distress type for four pavement types and four highway system classifications. The developed models provided good predictions and helped determine the remaining service life and pavement network health evaluation. Further research study is required to conduct comprehensive analyses of pavement treatment selection models based on LADOTD distress data and a scheme for the selection of the most cost-effective pavement treatment/preservation action based on the treatment performances and causes of distress. It is believed that findings of this study will enhance LADOTD's capabilities in predicting pavement performance and monitoring pavement network condition in a most efficient and cost-effective manner.

ACKNOWLEDGMENTS

The investigators wish to express their sincere thanks to the Louisiana Transportation Research Center (LTRC) and Federal Highway Administration (FHWA) for their financial support. A special thank you is extended to the Project Review Committee for their continuous help during the course of this study. Last but not least, they would like to express gratitude to the Pavement Management Systems group and all LADOTD engineers and managers at Headquarters and the various districts for their assistance and valuable inputs during the review process.

IMPLEMENTATION STATEMENT

During the second phase of the study, a comprehensive assessment and evaluation of pavement performance predictions models and treatment models were conducted. Various index based pavement performance models were developed that can be implemented by the pavement management system for network level analysis. The generalized models that are similar to the LADOTD family curves are based on the pavement age and can be implemented immediately.

On the other hand, the individual control section models and consolidated models require a plan for implementation. The remaining service life concept can be utilized for developing uniform pavement sections and evaluating the pavement network health and optimization of the strategies. The main advantage of using the remaining service life to divide the network into uniform pavement sections is that all pavement segments within any uniform section would have similar pavement conditions and rates of deterioration. The preliminary treatment performance model can provide guidelines for establishing the treatment life and developing a scheme for cost effective treatment selection. In short, the investigators believe that the recommendations of phase I and phase II of the study, once implemented, can enhance the pavement management system's capabilities in efficiently managing pavements and improving communication amongst the end users.

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INTRODUCTION

The pavement network of LADOTD is surveyed once every two years. The Automatic Road Analyzer (ARAN) vehicle collects roughness (International Roughness Index, IRI), rut, cracking (longitudinal, transverse, random, and alligator), patching, and faulting data. All Pavement Management System (PMS) data are collected based on two location reference systems that consist of control-sections subdivided into 1/10th mile segments and latitude and longitude coordinates. All districts in the state of Louisiana have access to all PMS data and the majority of them use it. LADOTD's PMS section conducts frequent meetings, seminars, and training sessions for district engineers to enhance the use and efficiency of the PMS data.

A two-year research study was initiated by LADOTD in conjunction with FHWA to evaluate the overall performance and effectiveness of LADOTD's PMS. In order to perform a comprehensive review and assessment of operation and implementation of the current PMS, the study was divided into two phases. The first phase focused on the assessment of the state-of-the-practice of LADOTD's PMS regarding accessibility, PMS reports, reference location systems, and distress indices. Part of the assessment was conducted through the analysis of the responses of all district engineers to specially designed survey questionnaires and personnel interviews. The details of first phase of the study can be found in LTRC Report No. 430. The summary of findings of the first phase has also been presented in this report. Most of the recommendations of the first phase of study have been either implemented or in the process of implementation by LADOTD.

This report focuses on the second phase of the study, which includes a review and update of both pavement performance and treatment models. During the second phase, a comprehensive evaluation and analysis of the pavement performance and treatment models were conducted using LADOTD pavement distress data and historical data. Statistical analyses were used to generate the model for pavement condition prediction and treatment performance evaluation. It is believed that findings of the study will enhance LADOTD capabilities in predicting pavement performance and the remaining service life, thereby, monitoring pavement network health in an efficient manner.

OBJECTIVE

The main objective of the research project was to find the most cost-effective way to incorporate PMS into LADOTD's regular operation and make the information in PMS usable for engineers within the Department (especially for district level personnel who schedule construction and maintenance activities). The objective of this study was accomplished as follows:

1. Identify the needs of PMS users at LADOTD.

2. Establish a unified roadway identification system acceptable to all PMS users.

3. Evaluate and update the pavement performance and treatment models.

Objectives 1 and 2 were a part of phase I of the study and have been discussed in detail in LTRC Report No. 430. Objective 3 was the part of phase II of the study and is discussed in this final report.

SCOPE

During the second phase of the study, a comprehensive evaluation and analysis of the pavement performance and treatment models were conducted. LADOTD pavement distress data and historical data were utilized to calibrate and develop project level and network level models. Once the main database was generated, the data were sorted based on various control sections. The main database was divided into four categories based on the highway system classification including the Interstate Highway System (IHS), National Highway System (NHS), State Highway System (SHS), and Regional Highway System (RHS). Each of these highway systems was further divided into four pavement types: flexible pavement (ASP), composite pavement (COM), jointed concrete pavement (JCP), and continually reinforced concrete pavements (CRC). The data analysis was conducted for each of the distresses (roughness, fatigue cracking, longitudinal and transverse cracking, and patching) for the respective pavement type. A statistical analysis was used to develop the regression model for pavement condition prediction and treatment performance evaluation. The developed models were utilized to predict pavement condition, the remaining service life to facilitate pavement network health evaluation, and uniform pavement section development. It should be noted that a comprehensive literature review was also conducted to facilitate pavement model development, analyses, evaluation, and remaining service life determination. Finally, based on the results and analyses of the data, various conclusions and recommendation were drawn.

METHODOLOGY

Background

Introduction

In an effort to evaluate and improve the PMS, LADOTD in conjunction with FHWA, initiated a two-year research study to evaluate the overall performance and effectiveness of LADOTD's PMS. In order to conduct a comprehensive review and assessment of operation and implementation of the current PMS, the study was divided into two phases. Phase I included the following:

- review and examine current PMS practices within the Department,
- conduct a departmental survey to identify the needs of PMS users,
- identify the available source of pavement data, and
- recommend a PMS roadway identification system.

Phase II included a review and update of both pavement performance and treatment models. This report focuses on the Phase II study.

Phase I

The first phase focused on the assessment of the state-of-the-practice of LADOTD's PMS regarding accessibility, PMS reports, reference location systems, and distress indices. Part of the assessment was conducted through the analysis of the responses of all district engineers to specially designed survey questionnaires and personnel interviews. The key efforts of the research team during the first phase of the study included:

- Review of the state-of-the-practice of the PMS of the LADOTD. The review included but was not limited to the current highway classification system, reference location systems, the distress data collection and storage practices, other data available in the Department, deduct points, distress indices and remaining service life calculations, and project- and network-level reports.

- Survey of all districts engineers to address districts' needs. The survey addressed various issues including: types of reports and the accessibility, the utility of PMS outputs, existing location reference systems, various pavement preservation actions, and degrees to which the PMS users fully understand the benefits and potential cost savings that can be precipitated by using PMS data.

The detailed description of all the analyses and results of Phase I can be found in the LTRC Report No. 430 *[1]*. For reader's convenience, the summary of the findings of the Phase I study are reported in the following sections.

Findings of Phase I

The following is the summary of the findings of the first phase of the study *[1], [2]:*

- LADOTD has an active and dynamic PMS. The pavement distress data are collected continuously (no sampling) for every $1/10^{th}$ mile segment and good data on pavement distresses are available from 1995 to 2007.

- All districts have access to PMS data and the majority uses the data.

- Although most districts view the overall IRI, the use of the data as reported by the district engineers varies substantially from one district to another. This can be overcome by obtaining inputs from district engineers and taking the proper steps to increase the use of PMS data. For example, values of distress indices and the remaining service life should be reviewed to determine whether or not they reflect actual conditions of pavements.

- No consensus was found amongst district engineers regarding the type of reports that they like to receive from the PMS office. New forms of reports should be developed that streamline the contents of the report to the audience. For example, network-level reports should be prepared for the managers and the legislators; whereas, project-level reports should target district engineers and technicians (include detailed engineering data).

- PMS data are also associated with GPS-coordinates (ARAN vehicle). In addition, the pavement inventory and historical data have electronic records (NEEDS, MATTS, TOPS, etc.)

- Although most districts have electronic records of maintenance and rehabilitation activities, data are not accessible or stored in the PMS databank. This may be due to:

    - Data are not accessible to the PMS unit.
    - Data forms are not compatible with the PMS data software.
    - The PMS data bank is not designed to store such data.

The main disadvantage of this is that PMS engineers cannot track the performance and the cost of the various pavement preservation actions. A meeting between the PMS unit and various district engineers should be held to discuss this issue. The meeting agenda may include:

- Types of data that are needed for a comprehensive and cost-effective pavement management. These include: fix type, cost, reference locations, and materials.
- The format and accuracy of data.
- Data quality control.
- The cost to unify all data forms versus available resources.

- Various location reference systems are being used; the majority of district engineers would like to convert to a unified location reference system although they have no concern about current referencing systems. This issue must be addressed at the Department and/or legislative levels. Linkage of existing location reference systems can be established using GPS. This would allow LADOTD to continue using existing systems. Linkage can be accomplished by utilizing already existing software developed by the computer section of the Department. However, the software has some limitations. Currently, it only links control section log mile (CSLM) and route mile post (RMP) with GPS. It should be further improved to link the remaining location reference systems. In addition, it can only identify the primary route.

- There is no standard procedure for establishing station number (STA) for projects. It is recommended to set up standard policy and procedures in the departments for establishing STA for future projects.

- The majority of district engineers are not aware of the implementation status of the previous FHWA recommendations *[1]*. The capabilities of the new distress data collection system and the PMS database are also not known. This suggests a lack of good communication between the PMS unit and districts. It is recommended that the PMS office should design and conduct training sessions and hold meetings with district personnel to train and update the PMS users regarding recent developments and capabilities of the PMS. This would enhance communication between PMS and districts.

- The deduct point policy has been modified twice since its establishment. However, no study has been conducted to calibrate the deduct points. This implies that the current scheme of deduct points should be calibrated and modified based on present knowledge and costs data.

- Distress data for various distress types are collected. Some of distress types such as random cracking can be confusing and include various types of cracks having different causes, hence different pavement preservation actions. LADOTD should eliminate the term “random cracking” from the list of distresses for flexible pavements. In addition, expand the distress types for flexible pavements to include: alligator cracking, transverse cracking, block cracking, full- and partial-depth patches, roughness, rut depth, and two categories of longitudinal cracks inside the wheel paths and elsewhere.

- The PMS establishes the pavement uniform sections based on the NEED section or project boundaries. It is recommended to explore other types of uniform sections that have more advantages (uniform sections based on one or more distress indices or remaining service life).

- LADOTD uses different threshold values (trigger values for preservation actions) for different pavement types and distresses. It is suggested to adopt a uniform trigger (threshold values) for all pavement types and for all types of distress in flexible, composite, and rigid pavements. Uniformity of threshold values for all pavement and distress types would enhance communication between districts and eliminate the need for establishing a dictionary for threshold values.

- In lieu of LADOTD efforts to implement the Mechanistic Empirical Design Guide (MEPDG), the following observations were made:

    - PMS data are fair/good for initial calibration of performance models (Level 2).
    - PMS data are not stored as required by MEPDG at the desired-level and in some cases at the minimum-level.

  It is recommended to calibrate the MEPDG pavement performance models for level 2 design using PMS data. Furthermore, consider establishing a satellite PMS/design database only for added new sections as recommended by FHWA.

All recommendations have been either implemented or in the process of implementation by the PMS section of LADOTD.

Literature Review

Pavement Condition Predictions

Predicting future conditions of pavements could be achieved by a successful performance model. Performance models could be used in determining future maintenance, rehabilitations, or reconstructions. A pavement deteriorates overtime. In the beginning stages, the rate of deterioration is gradual. In the middle stages, the rate of deterioration increases. In the final stages, the rate stabilizes at a very low index value. An extended pavement life is accomplished by resetting the distresses to a better index. When this is done several times, the life of the pavement is extended *[3], [4]*. Many transportation departments group similar type roads, considered "families," and models using regression techniques to determine deterioration patterns *[5]*. Also, performance models could be designed on two levels: network or project. Network-level models are more concerned with the big picture, meaning that a state would be assessed and modeled as a whole. Project-level models would minimize or localize prediction models to their specific needs.

In general, performance models are functions of age, traffic, surface type, climate, materials, and type of distress. Some of these models predict pavement conditions based on the distress index and have the following general form:

$$Distress\ Index = (Age\ or\ ESAL)^{a} * \{b(Design)^{c} + d(Soils)^{e} + f(Climate)^{g} + h(Materials)^{i}\} \quad (1)$$

where, a, b, c, d, f, g, h, and i are regression constants.

Most of the studies have been focused on pavement prediction because if the life of the road can be determined then the proper funding can be allocated *[6-10]*. The success of any pavement performance model is determined by its ability to predict future pavement conditions and choose optimum project boundaries and times to apply the most cost-effective treatment *[11], [12]*. Johnson et al. grouped different pavement types and conducted analyses to determine if the data needed any manipulation *[13]*. A linear regression model was first tried, and it was found that rehabilitation of roads caused the performance index to go up and then fall again. This problem was resolved by removing records in the analytical pavement section data base that are under the influence of rehabilitation. It was determined that the linear regression model was not generating optimal results. A nonlinear regression modeling technique was used to determine performance prediction models.

Roberts et al. looked at a design of zero maintenance flexible pavements *[14]*. They studied permanent deformation, fatigue cracking, and low-temperature cracking of the pavements. The economical impact analysis of zero maintenance flexible pavements was also examined. The study showed that a zero maintenance flexible pavement can be constructed, but the cost is significantly higher than if an efficient pavement management was implemented.

The pavement condition index, which is the numeric representation of the pavement condition in the field, has been used by the Washington State Department of Transportation (WSDOT) to determine the surface condition of rigid pavements. This index should have the same trends with time as field observations. For most pavements and locations, the pavement condition tends to deteriorate at an ever increasing rate with time. The basic WSDOT PMS damage model was developed to represent this trend quite well *[15]*.

$$PCR = C - mA^P \tag{2}$$

where,
PCR = pavement condition rating,
A = pavement age (time since construction or resurfacing),
C = model constant for maximum rating (100),
m = slope coefficient, and
P = "selected" constant that controls the degree of the performance curve.

The above equation is similar to the general form of the distress indices equation using deduct points.

$$Distress\ Index = 100 - \{Total\ Deduct\ Points\} \tag{3}$$

Deduct points are based on the type of distress, extent of the distress and severity level, and department of transportation policy. Comparing equation (2) and (3) indicates that the term "mA^P" represents a trend followed by deduct points.

In equation (2) the typical value for P ranges from 1.5 to 3, and values of between 2.0 to 2.5 are the most common. It has been shown that the trend of the distress deduct values can be developed by using a trend line from a Log-Log plot to expand deduct values beyond the engineering criteria point. Deduct values developed with this approach generally provide deterioration trends with a P value of 2.0 to 2.5. P values in this range provide a gradual downward trend in the early part of the curve with a more pronounced downward trend toward the end of the curve. This is similar to what is observed in pavement deterioration trends in the northwest environment of Washington *[15]*.

In an effort to expand its use of the pavement management tools to support maintenance functions, the Arizona Department of Transportation (ADOT) selected Stantec's Highway Pavement Management Application (HPMA) software to replace its pavement management system and retained Stantec's services for structuring, data loading, model development, and implementing the HPMA. A sigmoidal (i.e., S-shaped) form is used within the HPMA for modeling the pavement performance. This model form has a greater degree of flexibility in describing the deterioration of a section. The following is the sigmoidal model form used in the HPMA for performance prediction modeling *[16]:*

$$PSR = O - \exp\left[A - B.C^{\ln\left(\frac{1}{Age}\right)}\right] \tag{4}$$

In this model, *PSR* is the Pavement Serviceability Rating and *O* represents the initial condition of the pavement, immediately after rehabilitation (age zero). Age is the number of years since the last rehabilitation or construction activity. Coefficients *A*, *B*, and *C* are the parameters that define the model shape.

The flexibility of the sigmoid allows the models produced to be concave, convex, S-shaped, or almost linear. This has historically produced curves that sufficiently fit the data and describe performance.

Treatment Selections

Well-engineered and managed pavement preservation processes include rehabilitation and preventive maintenance programs. For each potential project, the programs must address the selection of project boundaries, time of construction, and feasible rehabilitation or preventive maintenance actions. Although the selection of the feasible alternative has an impact on the longevity of the pavement, the selection of space and time (project location and time of action) has a substantial impact on the engineering management of the pavement network.

Rehabilitation and preventive maintenance of flexible and rigid pavements can be accomplished using many treatment options including:

- Reconstruction
- Recycling (hot and cold)
- Structural (thick) and non-structural (thin) overlays
- Mill and fill
- Crack sealing; fog seals; and chip seals
- Thin cold-mix seals, including slurry seals, micro surfacing, and cape seals
- Joint and crack sealing
- Concrete spall repair
- Dowel bar retrofit
- Full-depth concrete repair
- Diamond grinding
- Patching
- Shoulder and drainage improvement

Cost-effective pavement rehabilitation and/or pavement preservation programs can be established if the programs are based on the following critical issues:

1. The selection of space (project boundaries) and the impact of said selection on the health of the network.

2. The selection of feasible pavement rehabilitation and/or pavement preservation options, said selection must be based on the type and severity of the distresses and the causes of the distresses.

3. The selection of the optimum time for action. Two factors impact the optimum time as follows:

    - The rate of flow of the paper work within the agency. For example, in some agencies, the time span between project inception and project construction is 5 years for rehabilitation and 3 years for preventive maintenance. Such timing hinders the selection of cost-effective pavement preservation programs. The above issue can be easily addressed and multi-year cost-effective pavement rehabilitation and preservation programs can be generated if the agency uses the pavement condition data and rate of deterioration to optimize the strategy at the network first. After such a strategy is established, projects can be selected by various districts that satisfy the optimum and cost-effective strategy.

    - The lack of information. There is generally a lack of information that quantifies the improvement in pavement performance achieved with preventive maintenance programs. There have been several studies of the cost effectiveness of preventive maintenance *[17], [19], [20], [21]*. According to Geoffrey, the frequency of application for various preventive treatments, other than crack sealing and thin asphalt concrete overlays, is 5 to 6 years *[22]*. Some studies have shown that placing preventive treatments at frequencies of 5 to 10 years is the most cost-effective strategy. Other studies showed that the cost effectiveness of the preventive maintenance program is three to five times better than that of reconstruction *[23-26]*.

The type of treatment applied largely depends on the distress and distresses that need to be taken care of for the treatment to be effective. For example, the crack sealing is effective when low to moderate cracks of the fatigue, longitudinal, and/or transverse type is encountered. Micro-surfacing is highly recommended as filler and minor leveling but not very effective for medium to high severity cracking *[27]*. The cost-effectiveness of the preventive treatment is based on their timely application and is mainly derived from agency's observational experience *[28]*. Eltahan et al. used the concept of survival analysis and evaluated the survival time for various sections of the Long Term Pavement Performance (LTPP) database for maintenance treatment *[29]*. The results showed that for 6 years pavement performance data, the chip seal outperformed thin overlays, slurry seals, and crack seals in controlling the reappearance of distresses. It should be noted here that survival time for a significant number of sections could not be estimated due to good conditions at the time of last survey. Lin et al. evaluated the preventive maintenance effectiveness of flexible pavements (SPS-3) sections of LTTP in Texas and concluded that the thin overlay was the best treatment to resist rutting and should be used on high traffic routes due to its high initial cost *[30]*. The chip seal had the most sections that performed well, and crack seal provided the best alternative for low traffic routes with sound pavement structure due to its low initial cost.

In the state of Louisiana, the preventive maintenance program involves the use of chip seal and micro surfacing. A study by Shah showed that the median Pavement Condition Indecies (PCI) of chip seal and micro-surfacing sections were about 75 and 85, respectively, after about 52 to 60 months of service (PCI: 100-86= Excellent, 85-71= Very Good, ……..10-0 = failed) *[27]*. About 70 percent of chip seals sections were in good condition, and most of the micro surfacing sections were in good to excellent conditions. Chip seal sections showed bleeding in 70 percent of the sections. This bleeding was due to a combination of factors relative to loss of aggregate, additional embankment, and/or excess asphalt. However, most skid numbers were in the safe range.

Khattak et al. evaluated effectiveness of preventive maintenance of flexible pavements based on actual pavement performance using the LTTP database *[31]*. Approximately, 127 SPS-3 sections were analyzed from the southern states and 48 sections were selected with good pavement performance record for further analysis. Five performance factors, average duration of fix (ADF), average slope of distress (ASD), average distress measure (ADM), overall performance factor (OPF) and pavement condition index (PCI) were used to assess the rank and effectiveness of preventive maintenance. The results showed mixed ranking using the five factors; however, the ranking for chip seal and slurry seal were quite consistent. Overall, the chip seal and slurry seal exhibited the best performances. Based on the average OPF and PCI values, the chip seal ranked the first followed by slurry seal, and crack seal was ranked the last. ASD values that represent the rate of acceleration of distress were very high for crack seal.

Advantages and Disadvantages of Distress Indices

The accuracy of any pavement distress index to express the pavement condition is a function of the distress points assigned to each type of distress based on its severity and extent. If one assumed that such distress points are accurate, then the benefits can be derived from the use of pavement distress indices include *[32]:*

1. The use of pavement distress indices permits the highway organizations to establish a standard critical threshold level below which a pavement is considered unacceptable and in need of major maintenance or rehabilitation. This critical value may vary with the functional classification of the pavement (e.g., Interstate versus farm-to-market roads). Further, for any distress index, it is possible to establish various threshold levels, each of which could trigger an appropriate remedial action such as maintenance, minor repairs, or major rehabilitation.

2. Any pavement distress index allows for better communications. For example, if the rating scale of the distress indices is 0 to 100 (100 = perfect pavement) and the threshold value is 60, a pavement section distress value of 55 should be universally understood.

3. Pavement distress indices can be used to rank roads and highways for their maintenance/ rehabilitation activities.

4. The values of pavement distress indices collected over several years can be used to determine deterioration rates of each pavement section/segment and of the pavement network. This would permit engineers to modify or calibrate their performance prediction models.

The shortcomings of pavement distress indices include:

1. The value of any pavement distress index reflects the pavement condition at the time of the data collection survey. The value of the index alone does not reflect the rate of pavement deterioration.

2. The values of the distress indices of newly preserved or reconstructed pavement sections are generally the same regardless of the design life of the preservation action.

3. Any prioritized list generated solely on the basis of values of distress indices without considering the pavement rate of deterioration can be misleading. It is possible that two or more pavement sections with the same distress index value could have significantly different deterioration rates as shown in Figure 1.

4. Since the values of the distress indices calculated based on pavement condition of a given year do not reflect the pavement design life or rate of deterioration, their use as a basis for developing one- or multi-year rehabilitation programs is misleading. In order to

comprehensively develop such programs, the distress index and the pavement rate of deterioration must be known.

5. Although several pavement sections may have the same value of distress index, their deterioration rates could differ significantly (see Figure 1). Hence, one section may fall below the threshold value in one year while the other may have an acceptable condition (above the threshold value) for several additional years.

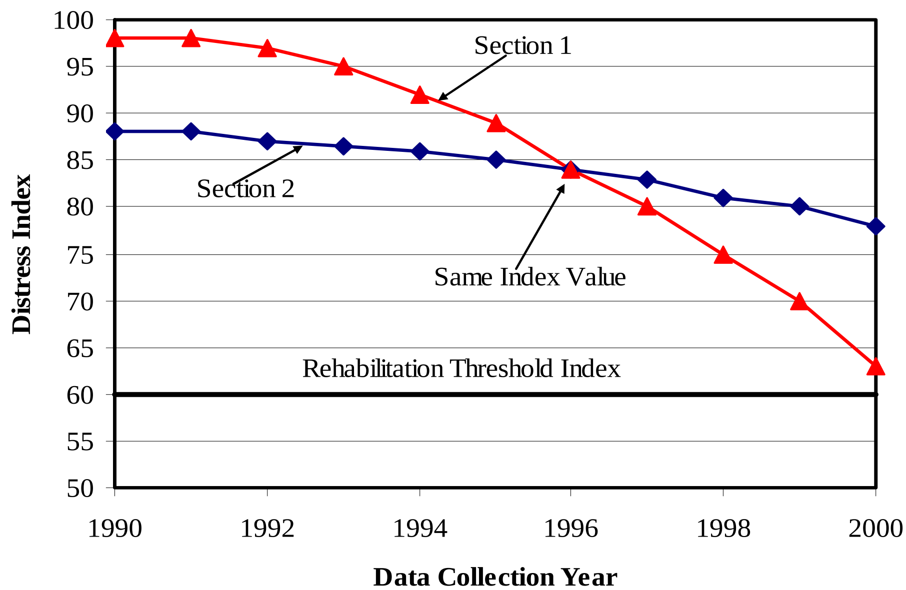


Figure 1
Historical pavement distress indices of two pavement sections

6. Distress indices alone cannot be used to assess rehabilitation benefits. For example, application of a one-inch or five-inch overlay may yield the same (short term) improvement in the distress index (no distress after overlay). However, the long-term benefits are likely to be different. Hence, rehabilitation benefits cannot be related to the improvement in the value of the distress index alone. The design life of the rehabilitation alternative needs to be considered.

7. Equating rehabilitation benefits only to improvements in the value of the distress index biases decisions in favor of cheap repairs (e.g., thin overlays). This may lead to a substantial growth in the number of pavement sections needing major rehabilitation.

8. Rehabilitation decisions based on distress indices alone would not help a highway agency control future conditions of its pavement network.

Remaining Service Life (RSL) Concept and Definition

The aforementioned shortcomings of the distress index can be eliminated, and its advantages could be enhanced if the following two steps were to be taken *[32]:*

- Examine the values of the distress index over a period of time (several years) to determine the pavement deterioration rate.
- Assign the initial value of the RSL (the value after rehabilitation) as a function of the design life of that rehabilitation.

The two steps can be combined by using the distress index values to calculate the RSL of each pavement section.

By definition, the RSL of a pavement section is the estimated/predicted number of years of service from any given date (usually from the last distress survey date) to the time when the pavement section is expected to accumulate distress points equal to the threshold value. For a network, it is the weighted average value of the RSLs of all the pavement sections in the network. The maximum value of the RSL is the design life of the last rehabilitation or construction and the minimum value of the RSL is zero. Negative RSL should not be assigned to any pavement regardless of its condition. For a newly designed and constructed or rehabilitated pavement section, the RSL is equal to the design life and the pavement or rehabilitation action. Finally, the service life (SL) of a pavement section is the actual number of years that the pavement is expected to serve the traveling public between construction and rehabilitation or between two consequent rehabilitation activities. Hence, the SL of any pavement section is equal to the sum of its surface age (SA) and RSL as shown in Figure 2.

Applications of Remaining Service Life

From the definition, it is clear that the RSL is a function of the severity and extent of the distress, the pavement rate of deterioration, and the design life of the rehabilitation option. Since the RSL combines the severity and extent of the distress and the rate of the pavement deterioration, the RSL can be used to:

- Estimate the RSL of the various pavement sections in the network and the weighted average RSL of the pavement network.

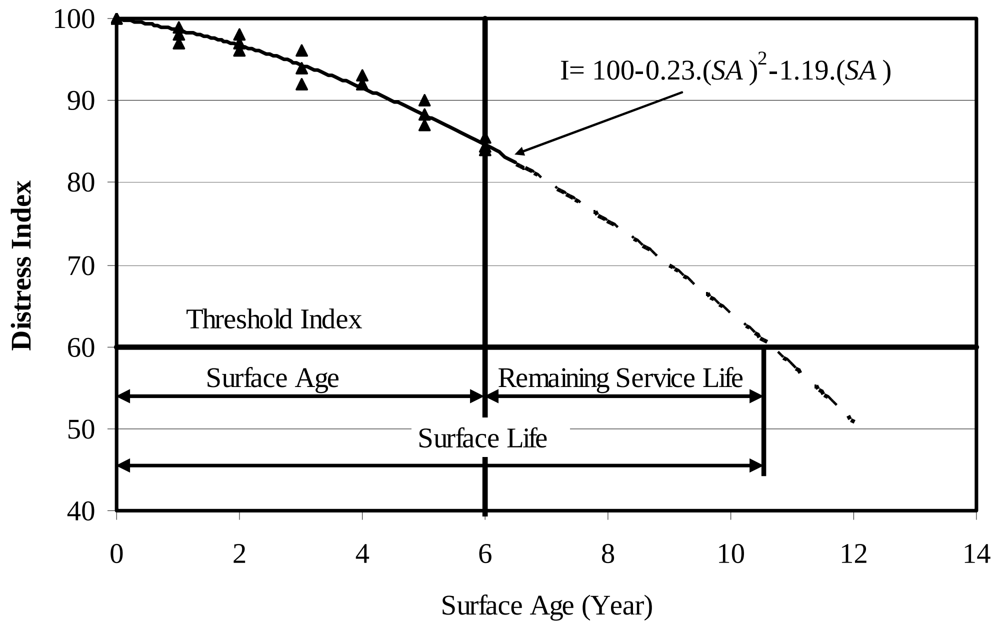


Figure 2
Typical remaining service life concept of pavement section

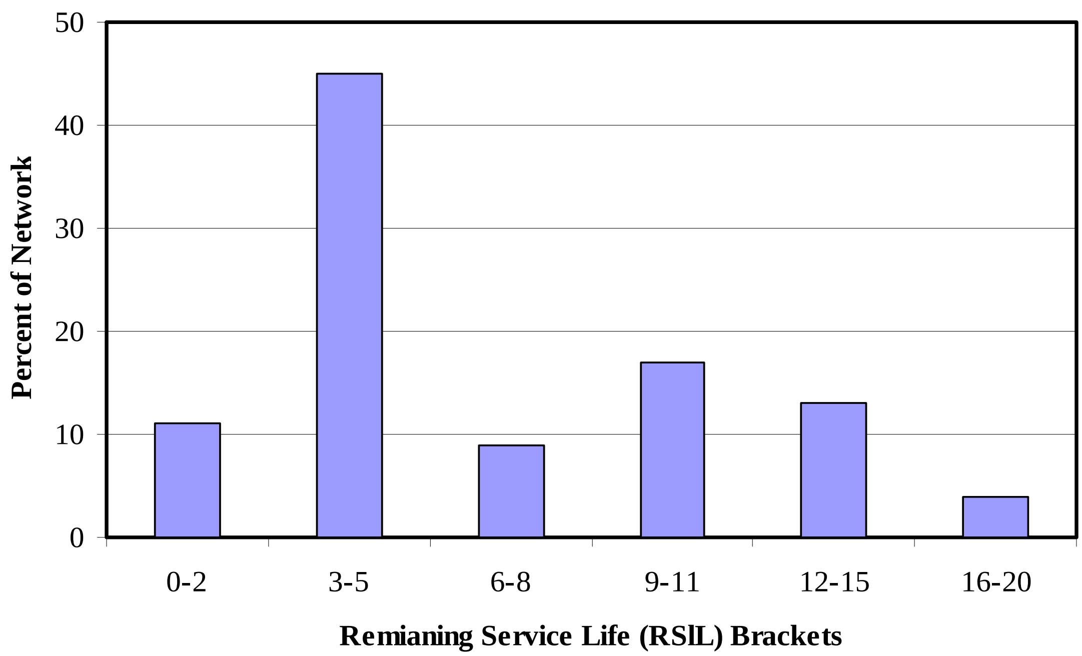


Figure 3
RSL distribution for a pavement network (uneven distribution)

- Calculate the percentage of the network in each RSL category (0, 1, 2, and 3 … years), hence determine the distribution of the RSL along the pavement network. It is also useful to define RSL time brackets (e.g., 0 to 2, 3 to 5, 6 to 8 ...etc.) and determine the percentage of the network in each RSL bracket as shown in Figure 3.

- Provide early detection of any unevenness in the distribution of RSLs over the pavement network (see Figure 3). For example, if the RSL of a high percentage of the network is 5 years, then the highway agency should expect its workload to increase within 5 years unless something is done to smooth out the RSL distribution.

- Estimate the true benefits of pavement preservation (RSL gained) for each pavement construction project.

- Calculate the value of the transportation asset in terms of lane-mile-year. This can be accomplished by calculating the weighted average RSL of the pavement network and multiplying the results by the number of lane-miles. For example, for a 9,000 lane-mile network having a weighted average RSL of 6 years, the value of the asset is 9000 (6) = 54,000 lane-mile-year.

- Assess the impacts of the pavement preservation program on the health of the network in terms of lane-mile-year gained or lost. To illustrate, a 9,000 lane-mile network will lose 9,000 lane-mile per year of service. If the pavement preservation program causes the network to gain only 4,000 lane-mile-year, then the network will experience a net loss of 5,000 lane-mile-year.

- Optimize the selection of pavement projects and preservation alternatives to maximize the number of lane-mile-year gained. Hence, the RSL can be used as an objective function in the optimization of the network preservation strategy.

- Generate one- and multi-year pavement preservation programs based on network needs and even distribution of the RSLs.

- Assess the impact of various budget levels on the health of the network. This can be accomplished by calculating the optimum number of lane-mile-year gained or lost due to each budget level.

- Enhance communication with legislators concerning network needs. For example, to maintain the status quo of a 10,000 lane-mile network, the annual pavement preservation program must receive, at minimum, funding sufficient to provide 10,000 lane-mile-year.

- Control the future condition of the pavement network. This can be accomplished by using a predetermined distribution of the RSL of the network as an objective function in the optimization calculation.

- Calculate the quantity (percentage) of the network user travel occurring on lower performing roads. In this calculation, any pavement section with zero or negative RSL values is a lower performing road.

Determination of Uniform Pavement Sections

In a typical pavement management practice, the pavement network is divided into various categories:

- Pavement type based on the pavement upper layer such as asphalt, composite, and concrete

- Pavement class based on traffic volume and weight, traffic control such as freeways and non freeways, road designation such as interstates and state roads, and so forth

- Uniform pavement sections based on the pavement conditions

The latter "uniform pavement sections based on the pavement conditions" is discussed in the following section.

Uniform Pavement Sections

In a pavement management practice, it is desirable to divide the pavement network into uniform pavement sections based on ranges of pre-specified parameters. Such division would assist state highway agencies (SHA) in managing the pavement network, analyzing pavement fix strategy, and selecting pavement projects. The most popular attributes used in dividing the pavement network into uniform sections are pavement conditions. Such divisions can be accomplished in three steps as follows:

- Establish ranges of pavement condition categories for dividing the pavement network into uniform sections. These categories could simply be based on distress types and severity, distress index or indices, and the remaining service life. This division should be accomplished free of constraints (political boundaries or jurisdiction, pavement type, and so forth) and will produce uniform pavement section categories. To illustrate, assume that the pavement conditions are divided into the six categories listed in Table 1; this would divide the entire pavement network into six uniform pavement section categories. Results of the divisions could be used to report the status of the pavement network (e.g., the percentage of the network in each RSL category or in excellent, very good, good, fair, poor, and very poor conditions).

- Divide each uniform pavement section category into uniform pavement section subcategories based on pavement type (flexible, composite, jointed concrete, continuously reinforced concrete). This would generate eighteen uniform pavement section subcategories. The uniform pavement section subcategories could be used for strategy analyses and optimization.

Table 1
Examples of ranges for uniform pavement sections based on various attributes

Attributes	**Pavement condition categories**					
	Excellent	**Very good**	**Good**	**Fair**	**Poor**	**Very poor**
Percent cracking	0 - 2	3 - 5	6 - 10	11 - 20	21 - 40	> 40
Distress Index	100 - 91	90 - 81	80 - 71	70 - 61	60 - 51	< 50
RSL (years)	> 20	16 - 20	11 - 15	6 - 10	3 - 5	≤ 2

- Identify each route number within a given political jurisdiction or boundaries of the uniform pavement section subcategories along that route. This would produce potential uniform pavement section candidate projects within given political boundaries (e.g., district, parish, and so forth). The resulting uniform pavement section candidate projects may or may not be contiguous; one uniform pavement section candidate project along a given road may consist of one or more pavement segments separated by other uniform pavement section candidate projects. In this scenario, various segments within one uniform pavement section candidate project could be counted as one project or can be divided into one project per segment depending on the length of the segments and the policy of the contracting office or the agency.

The above scenario implies that the process of dividing the pavement network into uniform pavement section candidate projects starts by dividing the entire network into uniform pavement section categories, which will be divided into subcategories based on pavement type. The subcategories will then be labeled by route number and political jurisdiction boundaries, which would produce uniform pavement section candidate projects.

The aforementioned discussion indicates that the length of any uniform pavement section category, subcategory, or candidate project varies from short (1 one mile or less) to medium (1 to 5 miles) to long (more than 5 miles). In addition, any uniform pavement section candidate project may consist of one contiguous section to several pavement segments located along one route and within given political boundaries.

Once again, several methods are used to identify uniform pavement sections. Four methods and their advantages and shortcomings are presented next.

Identification of Uniform Pavement Sections

Various methods are used to identify uniform pavement sections. Each method is based on one or more constraints and has its advantages and shortcomings. The following four methods are presented below:

1. Uniform pavement sections based on a combination of the survey method and the pavement conditions
2. Uniform pavement sections based on construction limits, previous project boundaries, and political boundaries
3. Uniform sections based on one or more pavement distress indices
4. Uniform pavement sections based on the remaining service life

Uniform Pavement Sections Based on the Survey Method and Conditions. This method is typically used by the highway agencies whose method of pavement condition survey is based on sampling. For example, the distress survey starts at a mile marker and proceeds for a short distance such as 200 feet along the pavement. The conditions of the 1-mile long pavement (between 2-mile markers) are assumed to be the same as those of the 200 feet surveyed section. This would initially generate temporary 1-mile long uniform sections. If the adjacent miles (temporary uniform sections) are within the same political boundaries (district or parish) and their conditions are more or less similar (within pre-specified percentage points), two or more temporary uniform sections are combined to form a longer uniform section (a pavement project) within one political jurisdiction. It should be noted that any of the 1-mile long temporary uniform section is not unique. Other 1-mile long pavement sections located throughout the pavement network may have similar conditions. Hence, they belong to the same category of uniform pavement sections. Once again, the 1-mile segments forming the uniform sections may or may not be contiguous.

The advantages of this method include:

1. The method is simple and based on the least possible pavement distress data collection efforts.
2. The method is flexible, yields both long and short uniform sections, and accommodates political and/or other types of boundaries.

The shortcomings of this method include:

1. The method may yield uniform sections where pavement conditions within any one uniform section is highly variable. This is mainly due to and is highly dependent on the sampling procedure used in the data collection process. A shorter sampling segment per mile yields higher variability. In the cases where the end mile marker is within less than 1-mile from jurisdictional boundaries or a bridge, the pavement surface conditions are typically assumed equal to the conditions of the previous 1-mile pavement. In such scenarios, the variability of the pavement conditions within the more than 1-mile long pavement section increases.
2. In case of re-alignment, historical distress data would be lost.

Construction Limits and Project Boundaries. In this method, boundaries of uniform sections are predetermined and based on daily construction limits and project boundaries. This implies that boundaries of uniform sections are static in nature and independent of pavement conditions.

The main advantage of this method is the static boundaries of the uniform section. Overtime, state personnel become familiar with boundaries of each uniform section. The disadvantages include:

1. Various degrees of variation in the pavement conditions may exist within any one uniform section. Consequently, a cost-effective pavement preservation program cannot be generated. Stated differently, the method does not have the flexibility to divide an old project into two or more projects based on pavement conditions.
2. In general, the method generates longer uniform sections for asphalt pavements than for concrete pavements.
3. Variations in pavement materials (e.g., roadbed soils, base materials, etc.) are likely to exist within the project construction limits. Hence, the cause or causes of pavement deterioration within a given uniform section may be substantially different.

The previous disadvantages can be minimized or eliminated by using one or a combination of the following constraints:

1. A uniform pavement section should have similar material types. This implies that design sections (a pavement section typically designed to have the same materials and roadbed soil) are superimposed on construction limits.
2. Pavement conditions along a control section should not vary by more than a prespecified percentage value. This implies that the construction limits method is constrained by boundaries of design sections and pavement conditions.

Pavement Distress Indices. In this method, boundaries of uniform pavement sections are selected based on one of the following alternatives:

1. Specific ranges in values of an individual pavement distress index, such as ride index, rut index, alligator cracking index, transverse cracking index, etc.
2. Specific ranges in values of a combined distress index (a distress index based on more than one distress type), such as surface distress index, structural distress index, and so forth
3. Specific ranges in the value of the overall pavement quality index or pavement condition index where all types of distress are included in the calculation of the index

The particular alternative and the number of indices to be used by the highway agency depend on the policy and objectives established by the agency and some constraining factors such as minimum project length, political boundaries, pavement type, and others. Each technique however has its advantages and disadvantages. For example, the main advantage of dividing the pavement network into uniform sections based on specific ranges in the values of one distress index (e.g., alligator crack index, rut index, or transverse cracking index) is that the type of pavement fix for each uniform section is the same provided the pavement has no other types of distress.

The determination of uniform pavement sections based on any one of the three alternatives listed above implies that the value of the index or indices within each control section is more or less uniform with some tolerance to certain variations. This can be illustrated by using the following example. Assume that the policy of a SHA calls for the division of the network into uniform pavement sections based on transverse cracking index, which is based on a scale from 0 to 100 (100 = no distress) and threshold values of 60 for major rehabilitation and 80 for preventive maintenance. Intervals along that scale (e.g., 41 to 50, 51 to 60, 61 to 70, 70 to 85, and more than 85) can be established such that adjacent pavement segments having index values within one interval are designated as one uniform pavement section. It should be noted that the intervals do not need to vary as shown above, they could be uniform. Indeed any intervals that are consistent with the policy of the SHA are desirable. Intervals along the index scale could be based on several criteria including:

1. The type and extent of the rehabilitation alternatives (crack seal, joint repair, resurfacing, etc.) required by each interval
2. The average cost of the rehabilitation alternatives required by each interval, implying that the cost of the alternatives varies between intervals

Finally, some of the constraints that could be imposed before a uniform pavement section is selected as a candidate project include minimum project length, political boundaries, and others.

The advantages of dividing the pavement network into uniform pavement sections based on the values of the pavement indices include:

1. It allows the SHA to identify candidate projects and feasible rehabilitation alternatives based on the condition of the pavement sections and their impact upon the overall conditions of the pavement network.
2. It provides flexibility in determining the uniform pavement sections with or without minimum or maximum length restrictions.
3. It enhances the ability of the SHA to compare the conditions of two adjacent uniform pavement sections and to analyze the impact of rehabilitating one without the other.

Regardless of the alternative specified in the policy of the highway agency, the selection of uniform pavement sections based on the values of any type of distress index may not lead to optimum and cost-effective pavement preservation program. The main reason is that two pavement sections having exactly the same distress index value may or may not have the same pavement conditions. Their rate of deterioration could be drastically different. Adding some constraints might improve the situation. Such constraints include:

1. The pavement within a given uniform section should have certain range of RSL values.
2. The pavement within a given uniform section should have a similar rate of deterioration.
3. The rehabilitation of the pavement within a given uniform section should have a similar impact on the overall conditions of the pavement network.

It should be noted that by using this system at the state network level, it is possible that one or more uniform pavement sections are located within two adjacent regions (political boundaries). In this scenario, the part of the uniform section located in region 1 will be a candidate project and the part in region 2 is another candidate project. The point herein is that one uniform section does not have to have contiguous boundaries or be located within the same region. However, if this scenario is not desirable, the situation can be corrected using one or a combination of the following two methods:

1. The control sections are located for one district or one region at a time.
2. A restriction based on the political boundaries is incorporated into the process of determining the locations of uniform sections.

Nevertheless, for good communication and for illustrative purposes, the final products of the system should include schematic strip maps along the pavement network whereby uniform sections are identified and the values of the pavement index/indices are superimposed on the maps. Using color-coding would enhance communications between various users.

Further discussion along with the analysis on the uniform pavement sections have been provided in the "Remaining Service Life and Uniform Pavement Sections" section of this report.

Research Approach

Research Plan

The overall research plan for this study is graphically depicted in the form of a flow chart in Figure 4. 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 LADOTD's 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) and project letting schedule (LETS) mainframe database. Both of these databases were obtained from the PMS section. The two databases were merged into one main database for model processing.

Once the main database was generated, the data were sorted into specific unique groups based on various control sections. The main database was divided into four categories based on the highway system classification including the IHS (Interstate Highway System), NHS (National Highway System), SHS (State Highway System), and RHS (Regional Highway System). Each of these highway systems was further 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 main database was utilized for data analyses of pavement conditions for various control sections. Some of the main database was used for data analysis of treatment performance. The data analysis of pavement condition was selected based on the control section number. On the other hand, the data analysis of the treatment performance was conducted based on the project number for the three treatment types including chip seal, microsurfacing, and thin overlay. The data analysis was done for each of the distresses for the respective pavement type.

Statistical analysis was used to develop regression models for pavement condition prediction. Various transformation functions were examined for each respective pavement type, highway classification, distress type, and control section. Statistical analysis was also used to generate the model for treatment performance evaluation. The developed models were utilized to predict pavement condition and the RSL (remaining service life) of the pavement section. It should be noted that a comprehensive literature review was also conducted to facilitate pavement model development, analyses, evaluation, and RSL determination. Finally, based on the results and analyses of data, various conclusions and recommendation were drawn.

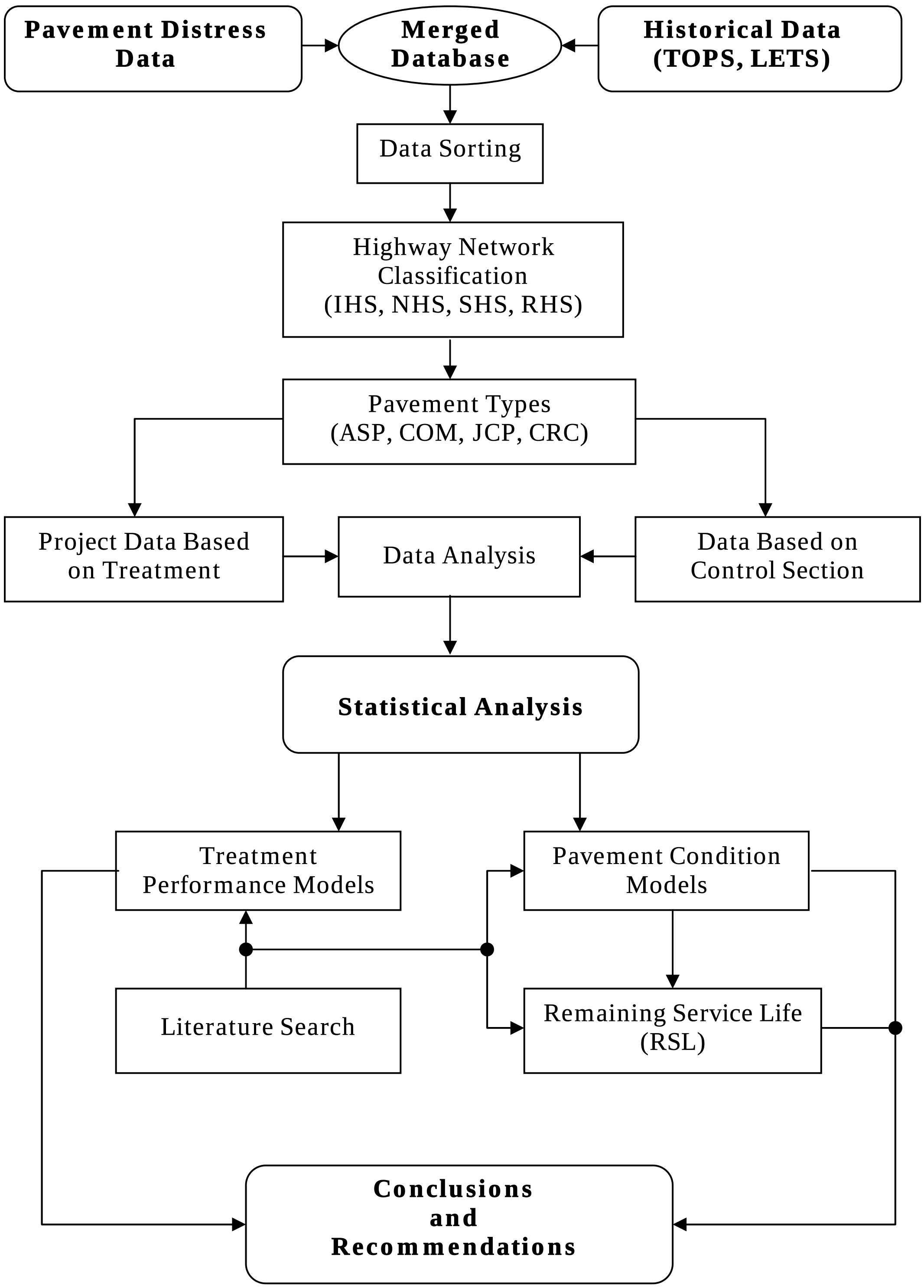


Figure 4
Flow chart representing the research approach for the study

Data Source for Pavement Performance Modeling

The historical pavement data were obtained from the LADOTD's mainframe database. The section of the mainframe that contains reconstruction and rehabilitation dates is located in the TOPS. The pavement distress data have been recorded every two years since 1995 by the automatic road analyzer (ARAN) and is stored in the PMS database. Although the ARAN vehicle is equipped with a GPS unit, all data are reported every 1/10th of a mile based on a location reference system that consists of control sections subdivided into log-miles. It must be noted that the data is recorded at every 1/100th of a mile and is averaged every 1/10th of a mile. This 1/10th of a mile is referred to as an element ID. Since the distress data have been collected every two years and the last data collection for the current study was 2005, this generated five points per element ID to work within the regression analysis. It should be noted that LADOTD uses Deighton Total Infrastructure Management System (dTIMS) software to analyze the pavement condition and to model the pavement rate of deterioration. The breakdown of data based on highway system classification and pavement types is summarized in Table 2 and Table 3. It can be seen from Table 3 that approximately 1-million points were available in the database to sort and analyze.

Table 2
Total mileage based on highway system classification and pavement types

Highway Classifica-tion	Pavement Type							Total
	Asphalt	Composite	Jointed Plain Concrete	Continuously Reinforce Concrete	Brick	Gravel	Un-known	
IHS	216	302	850	35	-	-	385	1,788
NHS	494	1,045	418	2	-	-	378	2,337
RHS	6,310	539	201	0	-	86	211	7,347
SHS	4,924	1,934	367	0	0	1	312	7,538
Unknown	46	4	2	-	0	0	39	91
Total	11,990	3,824	1,838	37	0	87	1,325	19,101

The historical data from TOPS was obtained for each control section and was broken down into every 1/10th of a mile. This has proven to be the most tedious element of the data analyses. The two pieces of data retrieved from the historical data were the reconstruction year and resurface year. The reconstruction year is the last year that reconstruction or major rehabilitation was done, such as pavement replacement and base/sub-base stabilization. The time period starting from the reconstruction year was referred to as "age" of the pavement. The resurface year is the last year the minor rehabilitation was done, such as overlays, etc. Similarly, the time period starting from the resurface year was referred as a “surface age” of the pavement. For each year PMS data was collected, the resurface year was reported in the database.

Table 3
Summary of data points based on highway system classification and pavement types

Highway Classifica-tion	Pavement Type							Total
	Asphalt	Composite	Jointed Plain Concrete	Continuously Reinforce Concrete	Brick	Gravel	Un-known	
IHS	10,805	15,090	42,502	1,749	-	-	19,250	89,396
NHS	24,676	52,256	20,889	118	-	-	18,882	116,821
RHS	315,512	26,934	10,058	4	-	4,288	10,539	367,335
SHS	246,177	96,717	18,354	7	15	50	15,603	376,923
Unknown	2,319	200	108	-	4	4	1,964	4,599
Total	599,489	191,197	91,911	1,878	19	4,342	66,238	955,074

Regression Analysis

In order to facilitate the regression analyses the first month, data points were also generated for each control section by a linear interpellation between the zero year and first year in a group for which the data was available. Each time the resurface age changed, this started a new group, thus generating another first month data point for the control section. Once all data were generated, it was reorganized for the regression models in an Excel spread sheet. The reorganization was done by placing each resurfacing year and the year the PMS data were recorded into an ordered pair. In addition to the reconstruction year, the control section and element ID had to remain associated with the appropriate ordered pair. Throughout the data, there were indexes, reconstruction years, and resurface years missing (such data were disregarded).

Typical raw data of rut index (RTI) based on the collection year and shifted data based on historical information for a control section of SHS are shown in Figures 5 and 6, respectively.

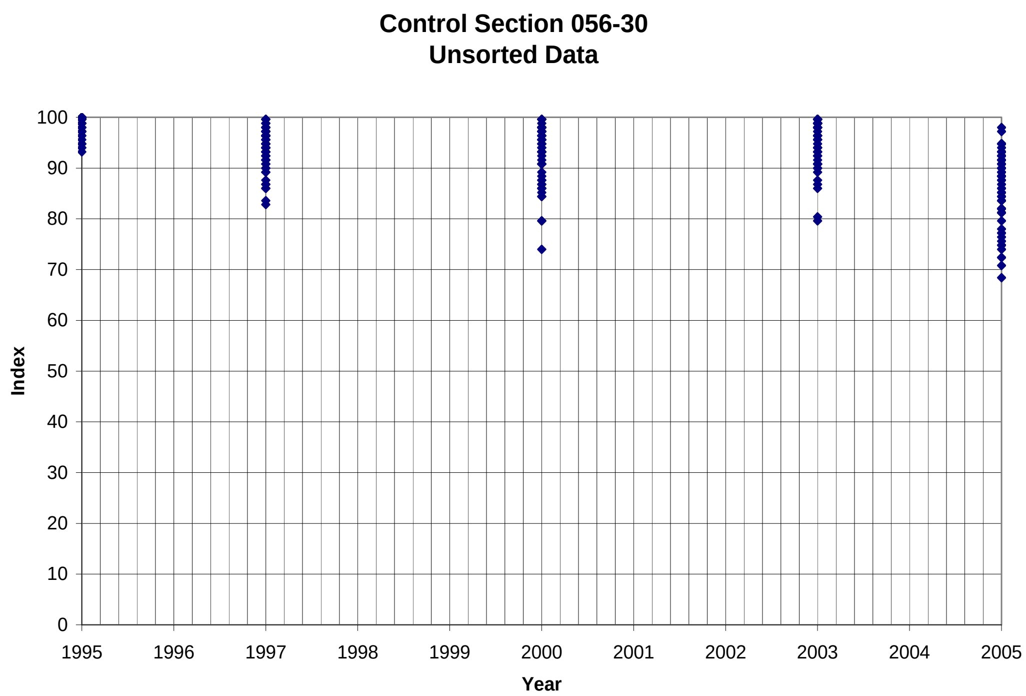


Figure 5
Rut index values based on data collection year for a control section of SHS

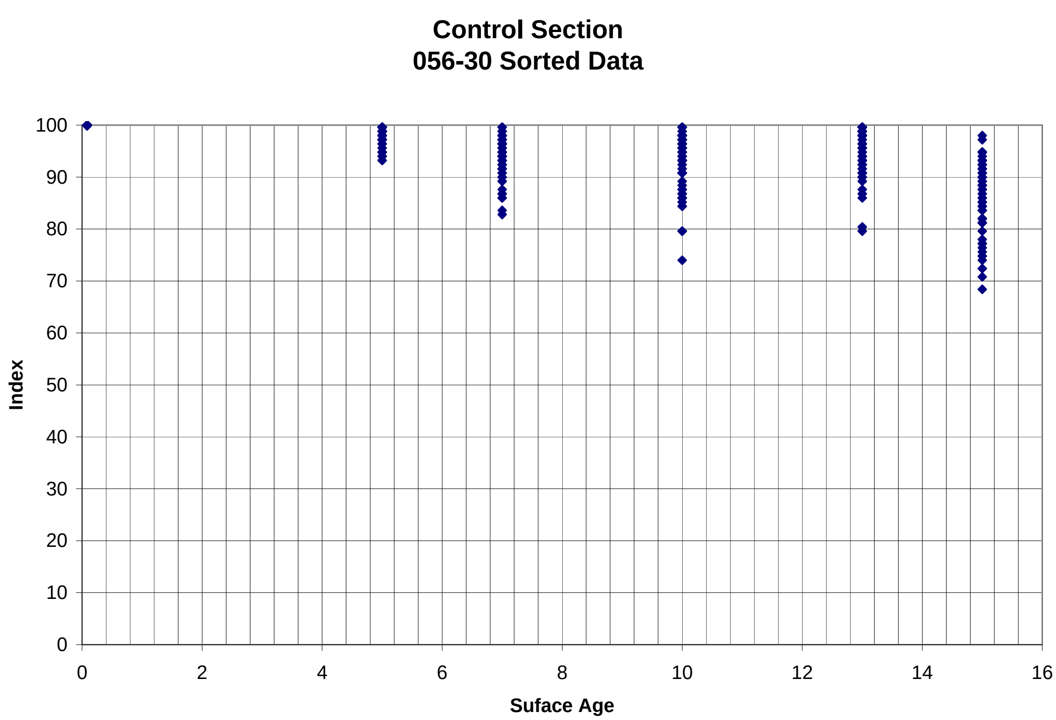


Figure 6
Shifted rut index values based on historical resurface year for a control section of SHS

Figure 5 shows the typical RTI values for all IDs (1/10th mile) of a control section for the collection years starting from 1995. The figure shows a significant scatter in the RTI values for a given control section. This indicates that each 1/10th of a mile of the control section behaves differently. Furthermore, the same control section has different resurface years. Therefore, the data was shifted using the historic age information based on the resurface year.

The PMS data collection year minus the resurface year was called as the surface age (SA). Once the SA of each 1/10th-mile section was determined, the distress index was plotted as a function of SA. Since the SA of each section varied due to the rehabilitation actions, it resulted in shifting of the data left or right on the x-axis based on the SA. Hence, the shift took into account the rehabilitation actions performed on various sections of the control section. Figure 6 illustrates the results of the shifted data for the same control section. It can be seen that except for a few points this shift depicts a good trend, which is a representative of the RTI verses time. The shift based on historical age information produced a data set for 15 years instead of 10 years.

Once the data was prepared, a regression analysis was conducted using the statistical analysis program called "R program." The following six distress types were considered for ASP and COM pavements:

- Longitudinal Cracking
- Transversal Cracking
- Fatigue Cracking
- Patching
- Rutting
- International Roughness Index (IRI)

For JCP and CRC pavements, all the above but fatigue cracking were considered for modeling. In addition, for each distress type, the following four regression models were analyzed:

- Exponential Function
- Logarithmic Function
- Power Function
- Two-degree Polynomial Function

The previous models were generated for the deduct point (P), which is 100 minus the index value. This is easier to model because at the beginning of the pavement life the index should be 100, thus the deduct point should be zero, putting the beginning of the model at the origin of the graph.

When the surface age data was plotted, it was found that in most cases there were a good set of points for each surface age for a given control section. As the surface age increased the spread of the data points also grew larger. This represented that each 1/10th of a mile section performed differently. In order to model pavement sections with similar behaviors and to reduce the effect of data scatter, each surface age data was clustered into three groups as:

- Upper One-Third Percentile
- Middle One-Third Percentile
- Lower One-Third Percentile

The regression models were developed for each distress type and each control section's percentile groups. Graphs were generated and examined as shown in Figure 7. A visual inspection of the graphs and regression models was also conducted to ensure the model followed the data trend. If two models correctly displayed the data, the correlation coefficient (R^2) and P-value were examined to select the final model. It should be noted that for each distress type (six distresses), four regression models for three percentile groups were generated. Since approximately 2,671 control-sections were analyzed, the regression analyses yielded numerous models. Only one model type was selected for each control section and each percentile group. The following criteria were adopted in accepting a model:

- Coefficient of determination (R^2) greater than or equal to 0.50
- P-value of less than or equal to 0.05
- Positive leading coefficient for polynomial regression model
- Positive exponent for power regression model

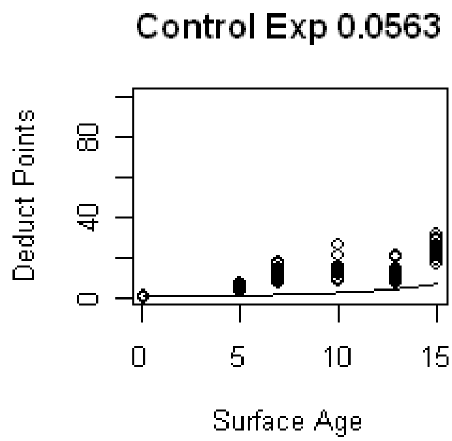
Criteria 1 and 2 will make sure that the model is statistically sound. On the other hand, criteria 3 and 4 will ensure that the model is acceptable based on the expected trend (engineering judgment). For example, a negative leading coefficient of the two-degree polynomial function and the positive power function will make sure that the pavement section deteriorates with time. It was found that the two leading regression models were the polynomial and the power functions. In general, the power function exhibited more promising results for the majority of control- sections.

Figure 8 shows a typical graph of RTI index for a control section along with three one-third percentile models. For this particular control section, the power function represented an actual data trend with good R^2 value.

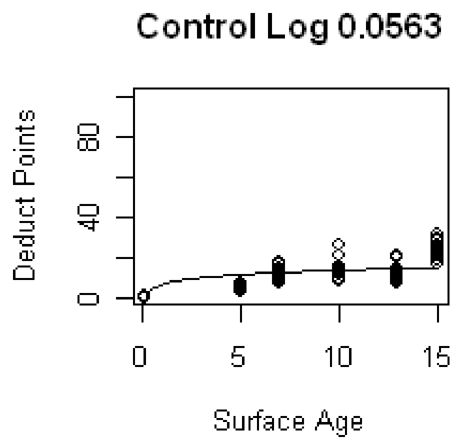
$$RTI = 100 - \left(b \cdot SA^{a}\right) \tag{5}$$

where, *SA* = surface age and *a*, and *b* are the regression coefficients for 1/3rd percentile models.

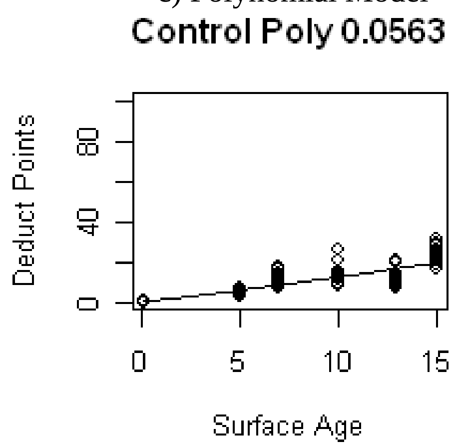
(a) Exponential Model



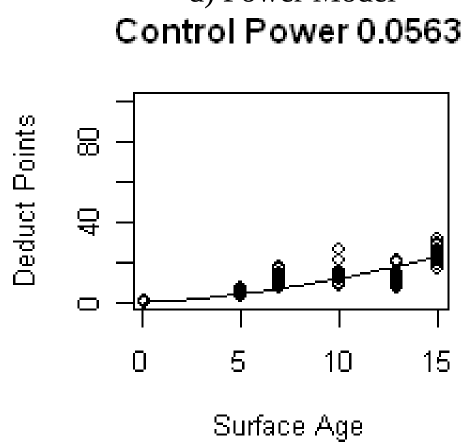
(b) Logarithmic Model



c) Polynomial Model



d) Power Model



Legends

Exp: Exponential Function
Log: Logarithmic Function
Ploy: Polynomial Function
Power: Power Function

Figure 7
Typical output charts of regression models using statistical analyses "R" program

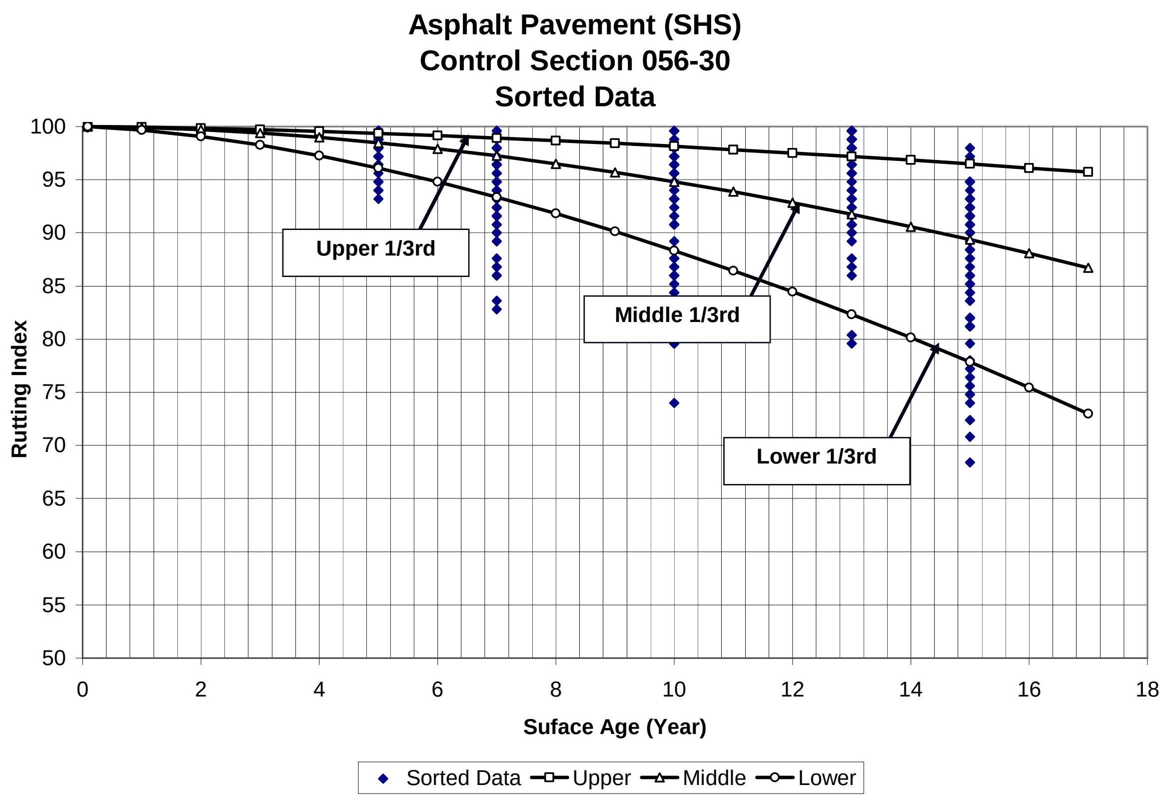


Figure 8

Typical plot of RTI index showing all the three 1/3rd percentile models

Consolidation of Pavement Performance Models

In order to accurately predict the pavement performance, it would be best to use the models developed for each control section. However, such a large number of models might not be practical to apply and use. Therefore, a model consolidation technique was applied to combine the models that exhibited similar behavior. Once the models were generated for each control section, they were reduced and combined based on the rate of deterioration. Recall that the deduct points (P) were modeled in the "R" program. The power function yielded the following form.

$$P = (10)^b (SA)^a \quad (6)$$

where, *a* and *b* are regression coefficients.

The previous equation can be written as:

$$\log(P) = a \log(SA)+b \qquad (7)$$

The previous equation represents a straight line in a log-log scale with *b* as an intercept and *a* as the slope of the line. The *a* coefficient indicates the rate of deterioration of the pavement section. Since, the rate of deterioration is important for pavement engineers, the coefficient *a* was grouped into 10 groups from 0.00 to 2.50 at an interval of 0.25 to facilitate model consolidation.

After the models were grouped into the above 10 sub-groups, an average model was produced for each sub-group. This was done by averaging all of the *a* and 10^b coefficient in that sub-group. Furthermore, the models were reduced by examining the predicted values at the 15th year, and the models that were outliers were removed. The outliers were determined by calculating the first and third quartile technique using the following set of equations:

$$\text{Prediction of the } i^{th} \text{ Model} = P_i(SA) = 10^{bi} \cdot SA^{a_i} \qquad (8)$$

$$\text{Prediction of the Average Model} = P_{avg}(SA) = \left(10^{b}\right)_{avg} \cdot SA^{a_{avg}} \qquad (9)$$

$$i = \begin{cases} \text{Round Up}\left(\frac{n}{2}\right) & for \quad n \in \text{Odd} \\ \frac{n}{2} & for \quad n \in \text{Even} \end{cases} \qquad (10)$$

$$\text{Median} = Q_1 = \begin{cases} x_i & for \quad n \in \text{Odd} \\ \frac{x_i + x_{(i+1)}}{2} & for \quad n \in \text{Even} \end{cases} \qquad (11)$$

$$l = \begin{cases} i-1 & for \quad n \in \text{Odd} \\ i & for \quad n \in \text{Even} \end{cases} \qquad (12)$$

$$j = \begin{cases} \text{Round Up}\left(\frac{l}{2}\right) & for \quad l \in \text{Odd} \\ \frac{l}{2} & for \quad l \in \text{Even} \end{cases} \qquad (13)$$

$$\text{First Quartile} = Q_1 = \begin{cases} x_j & \text{for } l \in \text{Odd} \\ \dfrac{x_j + x_{(j+1)}}{2} & \text{for } l \in \text{Even} \end{cases} \quad (14)$$

$$k = i + j \quad (15)$$

$$\text{Third Quartile} = Q_3 = \begin{cases} x_k & \text{for } l \in \text{Odd} \\ \dfrac{x_k + x_{(k+1)}}{2} & \text{for } l \in \text{Even} \end{cases} \quad (16)$$

$$\text{Upper Limit} = \text{P}_{\text{avg}}(SA) + 1.5 \cdot (Q_3 - Q_1) \quad (17)$$

$$\text{Lower Limit} = \text{P}_{\text{avg}}(SA) - 1.5 \cdot (Q_3 - Q_1) \quad (18)$$

where,
n = Number of Control Sections at the Prediction Year for each Sub-Group
$X = \{x_1, x_2, x_3, ..., x_n\} \mid x_1 \le x_2 \le x_3 \le ... \le x_n$
SA = Surface Age of the Prediction
a_i & b_i = Regression Coefficients for the i^{th} Control Section

The inter-quartile range was determined by subtracting the first quartile from the third quartile. One and a half times the inter-quartile range was added to the prediction of the average model for the upper limit and was subtracted from the prediction of the average model for the lower limit. After the outliers were removed, the average model was recalculated as previously stated. The iterations were repeated until there were no more outliers in any of the sub-groups. A complete stepwise example of the above process is presented in Appendix A.

A typical example of the initial process is illustrated in Figure 9. The figure depicts upper 3^{rd} percentile power models for fatigue cracking index (FI) of flexible pavement for a SHS. The *a* coefficient ranged from 1.50 to 1.75. After examining R^2, P-values and positive *a* coefficient the models reduced to 577 models from a total of 595 models. The quartile technique was then applied to remove any outliers at the 15^{th} year index value. Finally, after 14 iterations, the numbers of models were reduced to 487, a total loss of 108 models. The averages were calculated for both coefficients (*a* and 10^b) to determine the final average model that will be a representative of 487 control sections, as shown in Figure 10. The outliers can further be grouped and averaged to develop new models. For the previous example, the average model is shown next and a corresponding group of control sections are listed in Table 4.

$$FI = 100 - 0.04 \cdot SA^{1.621} \quad (19)$$

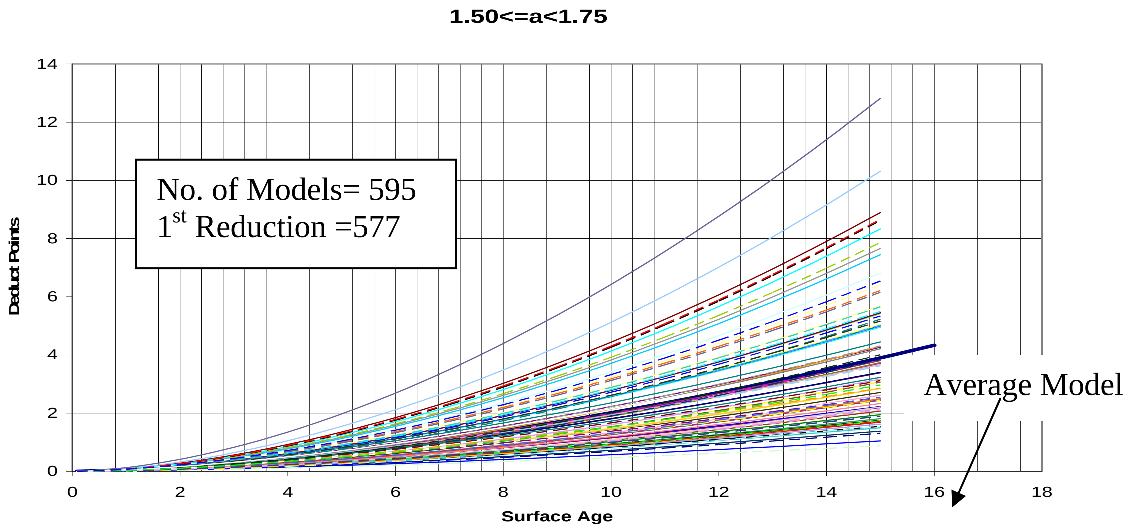


Figure 9

Initial model consolidation for fatigue cracking index model of ASP-SHS

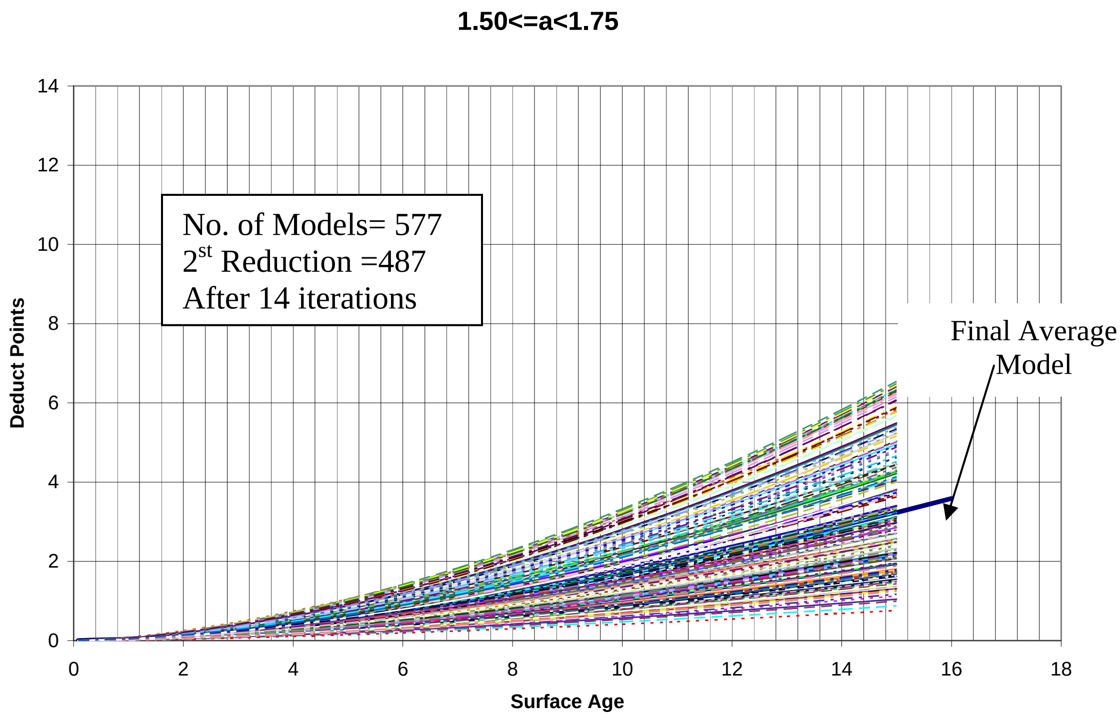


Figure 10

Final model consolidation for fatigue cracking index model of ASP-SHS

Table 4
Summary of control sections for upper consolidated model of fatigue cracking index for flexible pavements-SHS (a = 1.50 to 1.75)

$$FI = 100 - 0.04 \cdot SA^{1.621}$$

008-08	041-05	058-05	127-02	164-01	208-30	244-01	266-02	389-03
008-09	042-03	060-02	128-03	165-04	210-01	247-01	269-04	391-01
009-02	043-02	060-04	129-02	166-01	211-01	247-30	269-05	392-03
010-01	043-03	061-01	133-02	167-03	213-04	250-03	270-02	397-03
015-01	045-30	061-05	135-01	170-02	213-06	252-02	272-02	397-05
021-05	046-04	061-06	139-01	171-01	213-08	252-03	272-03	414-02
027-01	046-05	063-07	139-02	177-04	216-02	253-03	272-04	432-01
027-03	047-03	064-30	139-04	177-05	217-01	253-04	274-30	831-07
029-02	048-02	065-06	139-06	178-03	219-03	254-03	275-02	832-13
029-06	051-08	071-03	141-01	187-02	219-04	254-05	276-05	834-07
031-01	052-08	073-03	142-02	188-03	219-05	255-30	278-02	849-26
031-06	052-30	080-01	143-06	190-01	221-01	256-03	279-04	849-44
031-07	053-01	080-02	145-02	190-02	223-03	256-05	284-02	852-26
032-01	053-02	082-03	147-02	193-01	224-02	260-01	297-01	852-27
032-04	053-04	087-02	153-01	193-02	226-01	260-02	307-02	855-08
033-02	053-05	089-05	154-30	193-04	228-04	260-03	313-02	857-22
033-04	054-01	090-05	155-02	194-01	228-05	260-05	344-01	859-18
034-05	056-04	112-03	155-03	194-03	229-05	260-08	361-03	862-20
036-01	056-31	122-03	156-03	194-06	230-03	261-01	361-04	-
036-04	057-03	123-04	157-03	195-02	230-05	261-02	366-01	-
036-05	057-04	124-03	161-01	203-04	232-01	262-04	366-02	-
038-01	057-06	125-01	161-02	204-03	236-01	262-05	384-01	-
038-02	057-08	125-03	161-05	207-01	236-02	263-02	384-02	-
038-04	058-01	126-01	161-07	207-03	238-02	263-03	385-03	-
040-32	058-03	127-01	161-08	207-06	241-03	266-01	385-04	-

Generalized Pavement Performance Models

An effort was made to develop a generalized performance model for each distress index using the "age" of the pavements and data of all the control sections for each pavement type and highway classification. The age of the pavement is determined by subtracting the last year the data was recorded from the reconstruction year. For example (Figure 11), if the reconstruction year was 1980 and the last data collected was in year 2003, then the age of the pavement would be 23 years. Figure 11 also illustrates a typical pavement that has been subjected to various rehabilitation actions during its life span. The number of years between the reset index (100 or other) and the threshold index (60) value is called the surface age of the rehabilitation action. It can be seen from the figure that each time the pavement is rehabilitated the index value was reset to 100 or another value based on the rehabilitation type. Although the life span of the pavement has been extended due to each rehabilitation action, the rate of deterioration of the

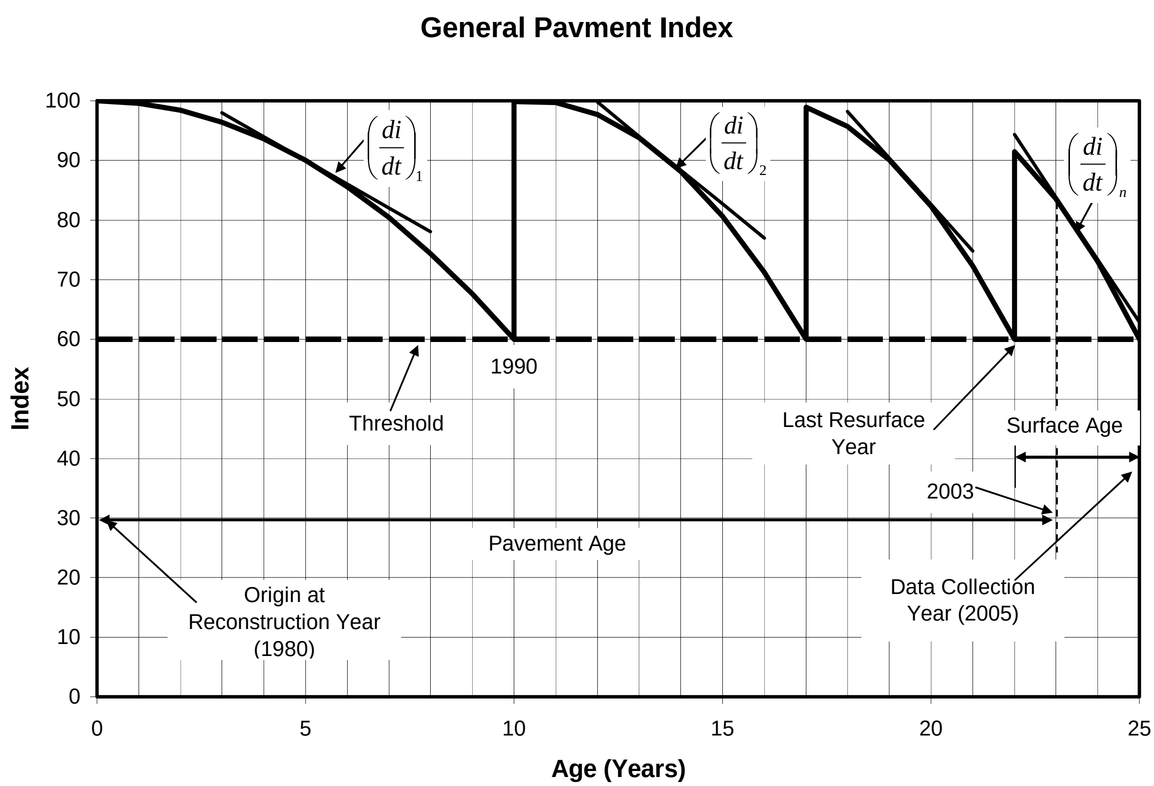


Figure 11
A typical pavement rehabilitation actions and deterioration models

pavement has increased with time. This implies that the average slope (*di/dt*) for each treatment performance model will increase with time as shown below:

$$\left|\left(\frac{di}{dt}\right)_1\right| < \left|\left(\frac{di}{dt}\right)_2\right| < \cdots < \left|\left(\frac{di}{dt}\right)_n\right| \tag{20}$$

where, *t* is the age and *i* is the index.

In order to develop a generalized model, the *di/dt* of the models developed for each control section can be determined and plotted as a function of pavement age. A transformation function can be obtained using regression analysis, which then can be integrated to develop the final generalized model as shown below.

$$I = 100 - P \tag{21}$$

where, *I* is the index and *P* is the deduct point. Differentiating the above equation yields the following:

$$\frac{dI}{dt} = -\frac{dP}{dt}$$

The above equation indicates that the slopes of the distress index and deduct point values are same but opposite in sign.

The *dP/dt* can be plotted as a function of pavement age (*t*) and regression analysis can be performed to obtain a transformation function, *f(t)*.

$$\frac{dP}{dt} = f(t)$$

The above equation can be integrated to determine the final function, *F(t)*.

$$P = \int dP = \int f(t) \cdot dt = F(t)$$

Hence, the final distress index model can be written as a function of age as follows.

$$I = 100 - F(t) \tag{22}$$

Based on the aforementioned concept, generalized pavement models were developed as a function of the "age" for each distress type, pavement type, and highway classification.

Figure 12 shows the average rate of deterioration (average of *a* coefficient, which is the slope of the curve in log-log scale) plotted as a function of average age of all the control sections analyzed for RI of flexible pavement for NHS. A spread sheet was developed in which the *a* values and associated "age" of the control sections were listed in ascending odder with respect to "age." The average values of *a* were calculated for an age group spaced at an interval of 5 years. This helped in reducing the data variation and scatter as shown in Figure 12.

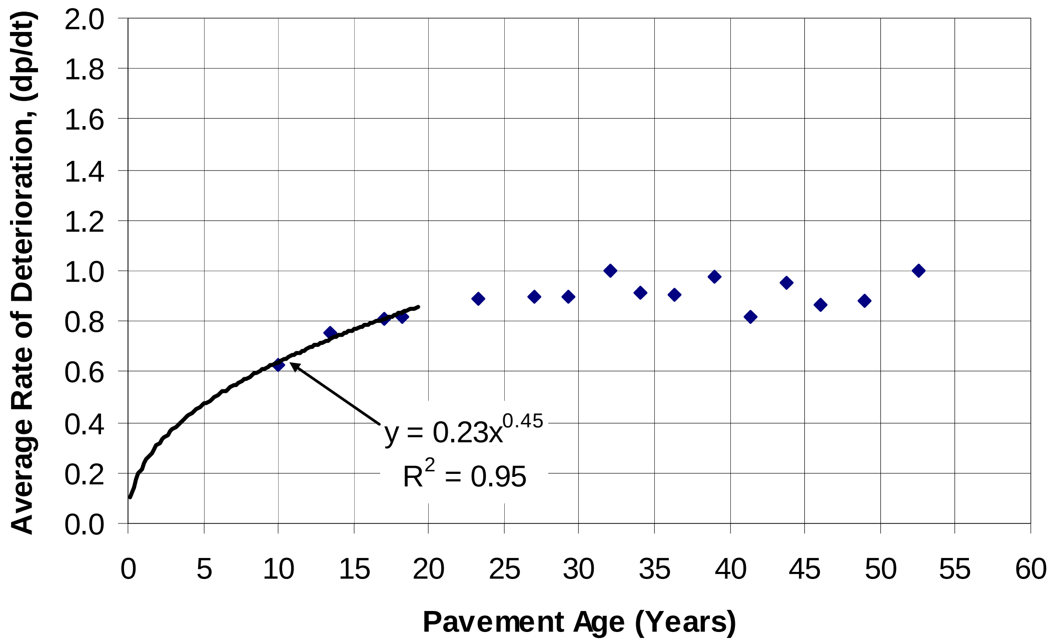


Figure 12

Average "a" coefficient values of the deduct points for generalized model based on average age

A best fit curve was applied to the initial portion of the curve and extended backward to determine the initial condition of the pavement (by interpolation). It is evident from the figure that the rate of deterioration (*a* value) increases as the age of the pavement sections increases, indicating that older pavements deteriorate at a faster rate. Figure 13 shows all the data points used for analyses along with initial data points calculated using the interpolation. Various transformation functions were applied to the data and the one that exhibited higher R^2 and P-values less than or equal to 0.05 was selected for further analyses. It was found that the power function fit the data well. The final generalized model was determined as follows:

$$RI_A = 100 - P = 100 - 10^{\left[B + b_1 .(t_A)^{a_1} \log(t_A)\right]} \quad (23)$$

where, RI_A = roughness index based on age, t_A = pavement age, and B = 0.125, a_1 = 0.25, b_1 = 0.35 are regression coefficients. The generalized model based on the age of the pavement can be used to determine the deterioration of a pavement section with successive rehabilitation actions during its life span.

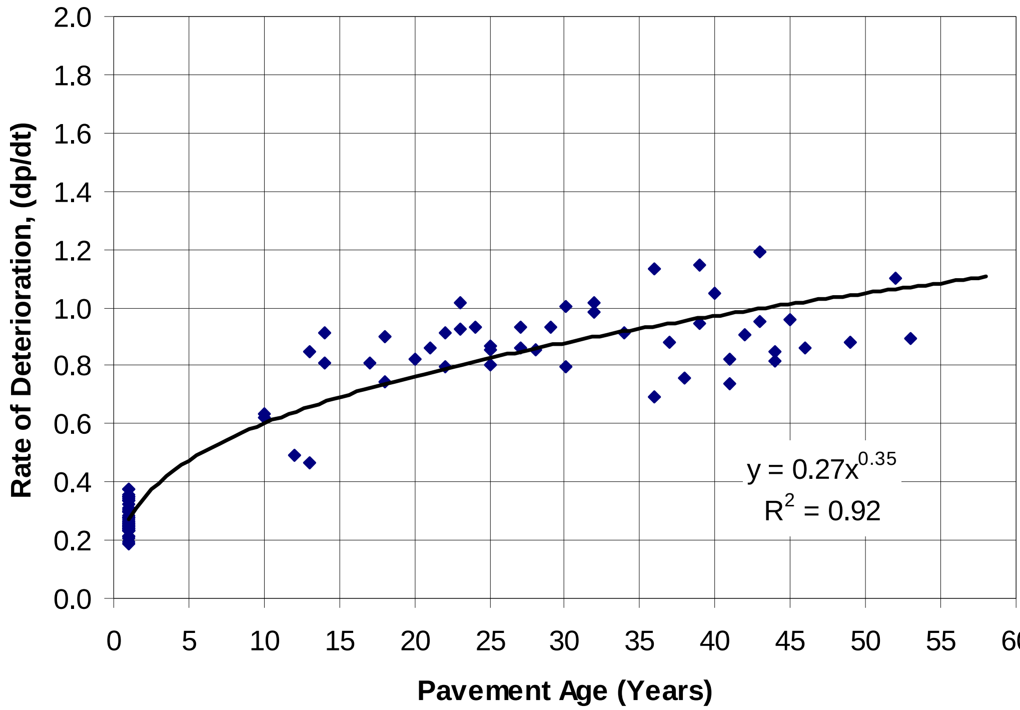


Figure 13
All “a” coefficient values of the deduct point models as a function of pavement age

In some cases when there were no good relationships between rate of deterioration and the age, a simple average of all the control section *a* coefficients was obtained and the model takes the following general form:

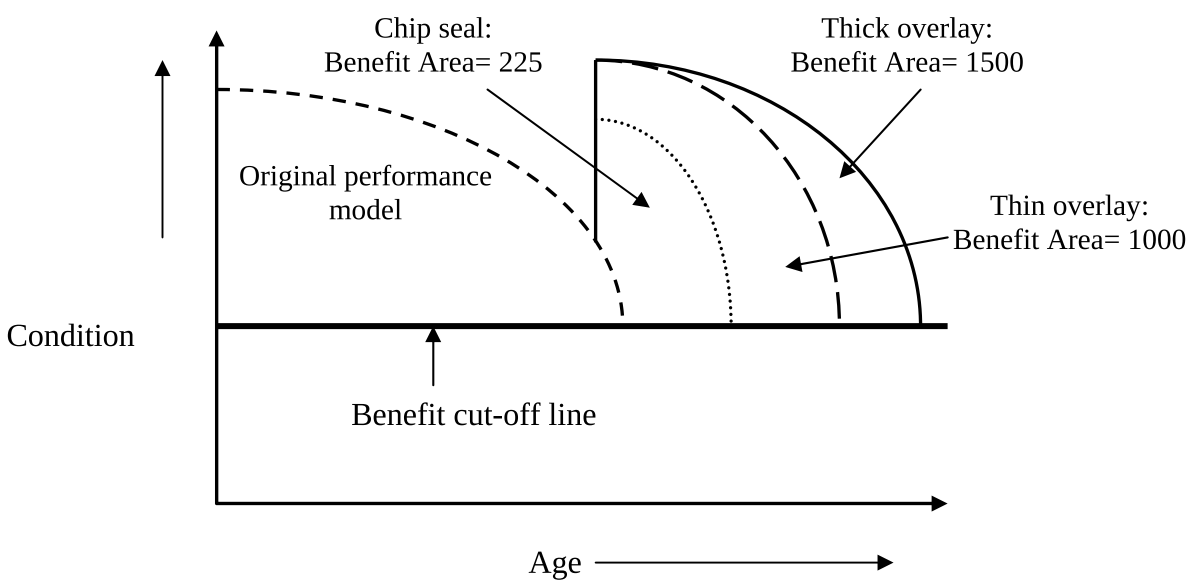
$$I = 100 - B_1 (t_A)^{a_{avg}} \qquad (24)$$

where, I = pavement index, a_{avg}= average of all *a* coefficients, and B_1= regression coefficient obtained by minimizing the sum of the squares errors. For flexible pavements, in general, roughness and rutting indices followed equation (23). On the other hand, cracking and patching indices exhibited mixed trends of equations (23) and (24) for all types of highway classifications.

Treatment Performance Evaluation

Final selection of the appropriate treatment for the section of the pavement depends on the type, cause and level of distress, and on the expected return from the treatment. The selection of the most appropriate treatments among all possible alternatives involves the use of the state-of-the-art practices, expert knowledge, state agency experience, benefit cost ratio, and performance history of the treatment.

For example, there are three feasible options for repairing a section of pavement: a chip seal, a thin overlay, and a thick overlay as shown in Figure 14. Since the thin overlay has the greatest benefit relative to the cost (cost-effectiveness ratio = 333 sf/$), it is the recommended repair type. This approach is illustrated in the following Figure 14. The above scenario indicates that it is imperative to evaluate the performance of various treatments and to develop the performance models for cost-effective treatment selection. The following section addresses performance evaluations and models for various treatments.



Treatment cost benefit ratio:

Chip seal	$2.25/sf	225	225/2.25	= 100 sf/$
Thin overlay	$3.00/sf	1000	1000/3.00	= 333 sf/$
Thick overlay	$4.75/sf	1500	1500/4.75	= 316 sf/$

Figure 14

Illustration of benefit-cost analysis using the performance curves of the treatment

Data Source and Sorting for Treatment Modeling

The original data were a bit overwhelming, but through steadfast and diligent study the data were understood. The pavement distress and historical data were extracted for chip seal, micro-surfacing and thin overlays using the merged database. The raw data consisted of the distress type, the severity level of each distress, and the rehabilitation history. Various rehabilitation projects identified by the Project Review Committee (PRC) were examined, and the projects with good pavement distress and history data were selected for the final analyses. Table 5 shows the list of all the selected projects for analyses. Using LADOTD's deduct points, the indices for fatigue cracking and patching were determined. For transversal and longitudinal cracking, the same deduct points as random cracking was utilized since random cracking is simply the summation of longitudinal and transversal cracking. This was accomplished by generating three excel files, one for each selected treatment type, the thin overlay, microsurfacing, and the chip seal. There were seven sheets per file. The first sheet was for the raw data, such as the element IDs, beginning and ending log miles, and the actual distresses broken up into the different distress levels. The next six were used to determine the indices of each distress type and other analysis. Another excel file was created for the input data for the "R" program.

The "R" program performed substantial repetitive analysis to generate data in a usable format. Note that the raw data in Excel sheets contained columns with a year heading (5 data collection years) and associated distresses or distress index for that year. The combination of such agreement produced 89 columns. However, the information required in the "R" program must have a single column with year information in ascending order and corresponding distress index data to perform modeling analysis. The routine developed in the "R" program simply decomposed the 89 columns in the input file into unique vectors, which allowed them to be recomposed into 23 columns for the final output. Hence, the purpose of the "R" programming routine was to breakup the five-year columns and replace them with a single year column, while keeping the respective data associated with the correct year. This was necessary so it would be easier to generate the graphs needed for the analysis.

Treatment Date

Although the pavement treatment dates were available in the merged database, the accuracy of some was questionable. This is because the plotted distress data as a function of time sometimes exhibited a sudden improvement, indicating that some type of treatment was applied on the section of pavement. Hence, the first aspect was to determine if there was a significant improvement when the pavement treatment was applied. This was accomplished by looking at the IRI data because almost all the distresses contribute to IRI values and then examining the distress pattern through the pavement history. In order to achieve this, the following steps were performed:

- Plot IRI against the control section log mile for each year.
- Plot the actual distresses against the control section log mile. A graph of each distress and distress level was plotted against the control section log mile.
- Plot a bar chart, of each distress and distress level for each year. On the same bar chart the average index for all the control section log miles of each year was plotted as a line graph from year to year. When calculating the average indices for all the control section log miles of each year, all indices with a 100 value were removed because the focus was to determine how the treatment held up against prior distresses.
- The average IRI for all the control section log miles of each year was plotted on the same graph with one standard deviation error bar from year to year. This comprehensive graph was generated for each distress and examined.

Table 5
Summary of treatment projects selected for analysis and modeling

Route	Control No	Log Mile			Pavement Type	Highway System	Remarks
		Begin	End	Miles			
LA-875	821-09	0.65	2.55	1.90	ASP	RHS	Chip Seal
LA-876	821-11	0	5.1	5.10	ASP	RHS	Chip Seal
LA-608	854-06	0	7.9	7.90	COM	RHS	Chip Seal
LA-608	181-02	1.93	5.93	4.00	COM	NHS	Chip Seal
LA-606	854-10	0.68	3.98	3.30	COM	RHS	Chip Seal
LA-564	813-01	0	4.85	4.85	ASP	RHS	Chip Seal
LA-126	353-03	0	2.3	2.30	COM	SHS	Chip Seal
LA-562	165-03	0	6.02	6.02	ASP	NHS	Chip Seal
LA-428	410-01	1.69	2.8	1.11	COM	NHS	Microsurfacing
LA-17	051-04	0	2.39	2.39	COM	SHS	Microsurfacing
I-20	451-07	11.01	17.49	6.48	COM	IHS	Microsurfacing
US-65	026-03	3.42	6.01	2.59	COM	NHS	Microsurfacing
LA-22	261-03	0	5.12	5.12	COM	SHS	Microsurfacing
LA-154	090-01	0	8.1	8.10	ASP	SHS	Thin Overlay
US-190	013-07	0	10.9	10.90	COM	SHS	Thin Overlay
US-71	010-06	0.3	8.2	7.90	ASP	SHS	Thin Overlay
LA-1023	832-04	0	4	4.00	ASP	RHS	Thin Overlay

Finally, a comprehensive graph was generated with all the average IRI, IRI standard deviation error bars, average indices of all the distresses and the total distress measurement for each level was produced. This final comprehensive graph was used to determine if there was a significant improvement when the treatment was applied and the time of treatment (Figure 15). It is clear from the figure that the distress intensity is significantly less in the year 1997. This indicates that some sort of the treatment was applied between 1995 and 1997. For this typical chart, an average value of 1996 was used as the time of treatment for the final analysis.

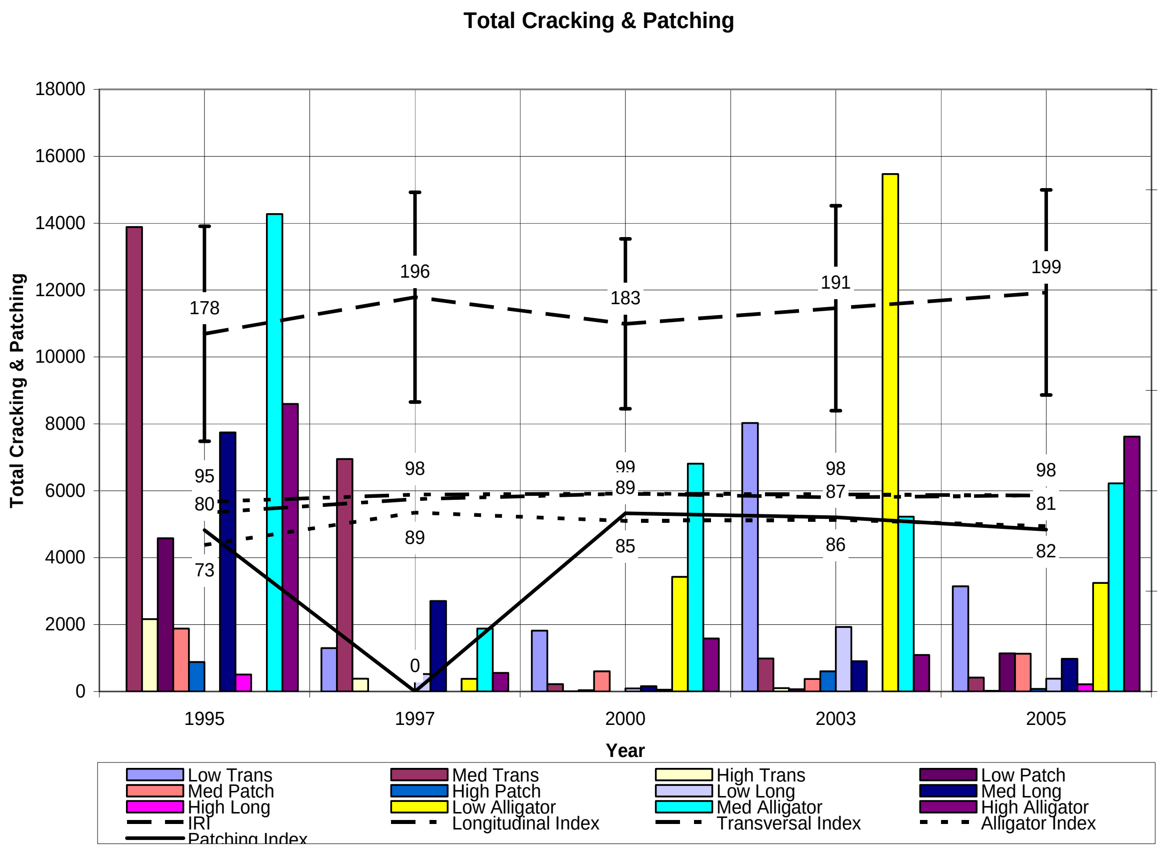


Figure 15

Typical cracking & patching chart for a chip seal project on a composite pavement

Statistical Analysis

Two regression models were examined for each treatment project. The first was to generally determine a regression model for the index. The index is simply calculated by subtracting the deduct points from 100. The second was to determine a regression model for the deduct points forcing it though the origin. This was done to test the assumption that the index for a newly resurfaced road should be 100, and consequently deduct points for a newly resurfaced road should be 0. The coefficients for each model should be the same but opposite in sign, and the intercept for the index model is 100, and the intercept for the deduct point model is 0.

Linear regression analyses were conducted to determine the regression models for treatments, and various outputs were obtained as shown below. 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, 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 6
Summary of regression output

Regression Statistics	
Multiple R	0.85
R^2	0.72
Adjusted R^2	0.71
Standard Error	2.74
Observations	95

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1732.9	577.65	77.22	6.36E-25
Residual	91	680.7	7.48		
Total	94	2413.7			

	Coefficients	*Standard Error*	*t-Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.896	0.623	1.439	0.153	-0.341	2.133	-0.341	2.133
SA^3	0.077	0.017	4.555	0.000	0.044	0.111	0.044	0.111
SA^2	-1.151	0.237	-4.850	0.000	-1.622	-0.680	-1.622	-0.680
SA	5.543	0.864	6.419	0.000	3.828	7.258	3.828	7.258

SA= Surface Age

Treatment Performance Modeling

Figure 16 is a typical graphical representation of the distresses and indices for a chip seal project on a composite pavement. The year prior to the treatment was excluded from the points to be modeled. First month data right after treatment application were also calculated by linear interpolation to facilitate regression modeling. If there was an evidence of additional treatment after the chip seal, that year and subsequent years data points were removed from the main dataset required for the modeling. Various transformation functions were examined, and one with good R-square, P-value, and reasonable trend was selected as a final model. In order to investigate the effect of treatment, the index distribution of the year prior to the treatment was also generated as shown in Figure 17.

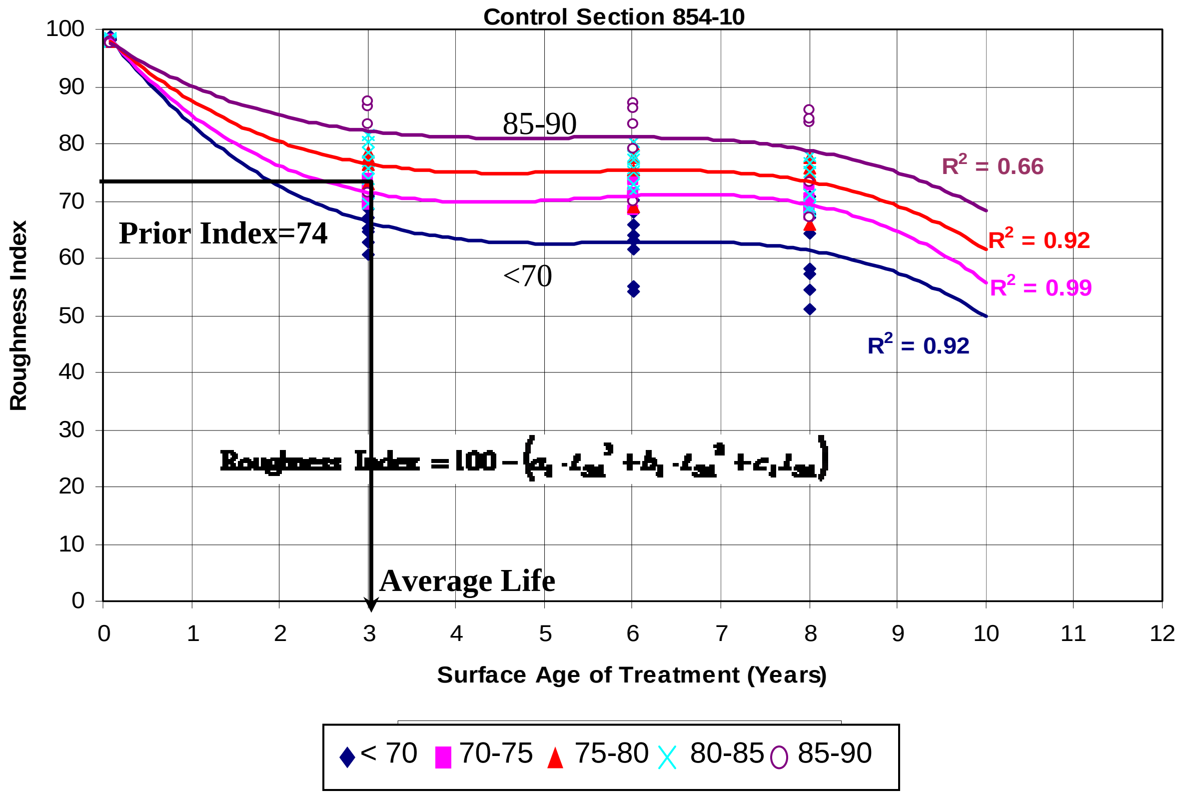


Figure 16

Performance model for a chip seal treatment on a composite pavement

Each element ID was clustered into subgroups based on the index distribution shown in Figure 17. After clustering data, each subgroup of element IDs was modeled uniquely by generating a regression model for the data set as shown in Figure 16. The control section shown in the figure was modeled using the 3-degree polynomial function. It can be seen from the figure that there is some overlap between the data points that were clustered based on prior condition of the pavement. Nevertheless, the models shown in Figure 16 indicate that for the same threshold values of either maintenance or major rehabilitation the pavement sections with higher index values prior to the treatment performed better after the chip seal treatment was applied. For example, for the maintenance threshold index of 85 the pavement sections with prior index of 85-90 required 2 years to reach maintenance threshold. On the other hand, the pavement sections with prior index of < 70 required less than 1 year to call for maintenance action.

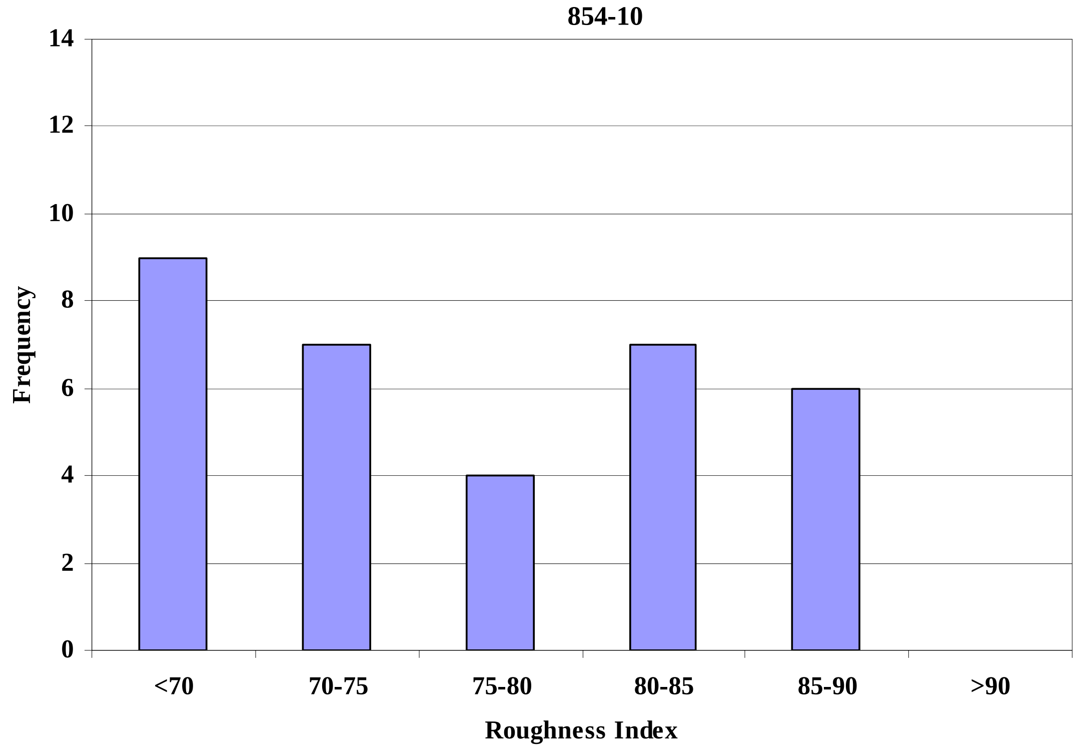


Figure 17
The index distribution of the year prior to the chip seal treatment

The aforementioned analysis also yielded the determination of treatment life. Treatment life is defined as the surface age at which the condition of the road (roughness index value) becomes the same as prior to the application of the treatment. For the control section shown in Figure 16, the average index values prior to chip seal treatment is 74. The data in the figure indicate that for the average treatment model it will take approximately 3 years for the pavement sections to reach the average index value of 74 (average index prior to the treatment). Hence, the life of the chip seal for the given project is 3 years.

DISCUSSION OF RESULTS

Existing LADOTD Pavement Performance Models

The main objective of any successful pavement performance model is to predict future pavement conditions to select the optimum space (project boundaries) and time to apply the most cost-effective treatment. The most accurate pavement performance model that can be applied to highway segment A is developed based on the historical condition data of that highway segment. Indeed, it is often stated in literature that a performance model developed based on condition data of highway segment A may not accurately apply to the adjacent highway segment B. Stated differently, each piece of pavement is unique.

The above scenario implies that, at the project level, the successful PMS will produce deterioration curve, performance prediction, and report based on the historical distress data of an individual project. One other point is that the prediction of pavement performance based on distress index may be misleading (i.e., two pavement projects of the same distress index may have substantially different deterioration rates and, therefore, different prediction times and cost).

The distress indices (I) are calculated using the deduct points (P) for each distress in a pavement using the following equation.

$$I = 100 - \Sigma P \tag{25}$$

The deduct points used by LADOTD are based on the type of distress, extent of the distress and severity level. For most distresses, three severity levels are used: low, medium, and high. For each type of distress, the cumulative deduct points for each 0.1 mile of pavement is then subtracted from 100 to calculate the distress index such as alligator cracking index, transverse cracking index and so forth. Hence, for all types of distress, the distress index is based on a scale from 0 to 100 with 100 indicating no surface distress *[1]*.

The distress index models currently used by LADOTD are based on at least 6 years of data collected at 2-year intervals. The models are a function of the "age" of the pavement that follows various transformation functions as shown below:

- Roughness Index: Polynomial Function
- All indices for CRC: Power Function
- Rutting Index: Exponential Function
- All other: Linear Function

Table 6 shows the summary of all the existing LADOTD pavement performance models for various pavement types, highway classifications, and distress types. For example, the LADOTD model for longitudinal distress index (LI) for CRC is a power function with the following form (Figure 18):

$$LI = 100 - a(Age)^b \tag{26}$$

where, a = 0.0173 and b = 2.6

Changing the values of *a* and *b* affects the slope and the degree of curvature of the resulting curve, respectively, as shown in Figure 18. Regardless of the type of performance model used within LADOTD PMS, the models themselves should be periodically reviewed and refined. Performance models directly impact the year a pavement section is selected for repair (Figure 18).

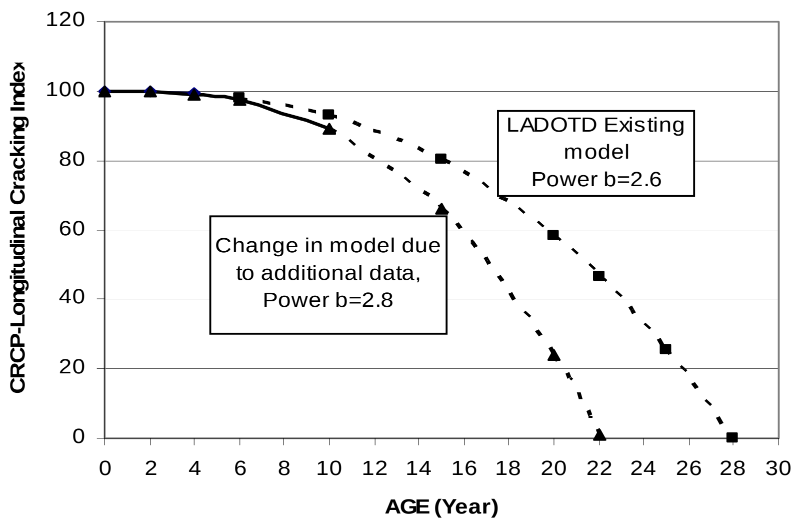


Figure 18
LADOTD model for CRCP LI for pavement condition assessment

Figure 18 also shows the change in model parameters with additional data. Models will be continually improved as the volume of historic performance data grows over time. Before a substantial historic database has been established, an expert opinion to obtain reliable performance models is required. As time goes by, however, and more performance data become available, there is less reliance on expert opinion, and the models can be calibrated by PMS engineers as soon as new data become available. The above discussion implies that it is imperative to evaluate and calibrate the existing LADOTD model to enhance PMS capabilities of predicting pavement performance. The evaluation of LADOTD models are discussed as follows.

Table 7
Existing LADOTD performance models

Distress and Pavement Type, and Highway System	Performance Models
Alligator Cracking Arterial Composite	100 - 0.3364 * AGE
Alligator Cracking Arterial Flexible	100 - 0.7027 * AGE
Alligator Cracking Collector Composite	100 - 0.6318 * AGE
Alligator Cracking Collector Flexible	100 - 0.6795 * AGE
Alligator Cracking Interstate Composite	100 - 0.2648 * AGE
Alligator Cracking Interstate Flexible	100 - 0.4172 * AGE
Longitudinal Cracking Arterial JCP	100 - 0.6649 * AGE
Longitudinal Cracking Collector JCP	100 - 0.4404 * AGE
Longitudinal Cracking Interstate CRCP	100 - 0.0172573 * AGE ** 2.6
Longitudinal Cracking Interstate JCP	100 - 0.4452 * AGE
Longitudinal Cracking Other CRCP	100 - 0.2317337 * AGE ** 1.76
Patching Arterial Composite	100 - 0.1504 * AGE
Patching Arterial Flexible	100 - 0.2130 * AGE
Patching Arterial JCP	100 - 0.5711 * AGE
Patching Collector Composite	100 - 0.2277 * AGE
Patching Collector Flexible	100 - 0.2628 * AGE
Patching Collector JCP	100 - 0.3272 * AGE
Patching Interstate Composite	100 - 0.0748 * AGE
Patching Interstate CRCP	100 - 0.0046376 * AGE ** 3.09
Patching Interstate Flexible	100 - 0.2183 * AGE
Patching Interstate JCP	100 - 1.0865 * AGE
Patching Other CRCP	100 - 0.0225589 * AGE ** 2.72
Random Cracking Arterial Composite	100 - 1.9675 * AGE
Random Cracking Arterial Flexible	100 - 1.6102 * AGE
Random Cracking Collector Composite	100 - 2.0816 * AGE
Random Cracking Collector Flexible	100 - 1.7534 * AGE
Random Cracking Interstate Composite	100 - 1.3101 * AGE
Random Cracking Interstate Flexible	100 - 1.6102 * AGE
Roughness Arterial Composite	0.0000000000000002 * (AGE) ^ 3 - 0.0149 * (AGE) ^2 - 1.2227 * (AGE) + 100.31
Roughness Arterial Flexible	0.0003 * (AGE) ** 3 - 0.0391 * (AGE) ** 2 - 0.7983 * (AGE) + 100
Roughness Arterial JCP	0.0000000000000007 * (AGE) ** 3 - 0.0046 * (AGE) ** 2 - 1.1775 * (AGE) + 99.35
Roughness Collector Composite	0.0000000000000004 * (AGE) ^3 - 0.0165 * (AGE) ^2 - 0.8809 * (AGE) + 100.22
Roughness Collector Flexible	0.0002 * (AGE) ** 3 - 0.0311 * (AGE) ** 2 - 0.5665 * (AGE) + 100
Roughness Collector JCP	0.0000000000000004 * (AGE) ^3 - 0.0105 * (AGE) ^ 2 - 1.2177 * (AGE) + 99.397
Roughness Interstate Composite	0.001 * (AGE) ** 3 - 0.0945 * (AGE) ** 2 + 0.0543 * (AGE) + 100
Roughness Interstate CRCP	-0.0004 * (AGE) ** 3 + 0.0104 * (AGE) ** 2 - 0.9005 * (AGE) + 100
Roughness Interstate Flexible	0.0003 * (AGE) ** 3 - 0.0391 * (AGE) ** 2 - 0.7983 * (AGE) + 100
Roughness Interstate JCP	0.0000000000000002 * (AGE) ** 3 - 0.0014 * (AGE) ** 2 - 1.2737 * (AGE) + 98.65
Roughness Other CRCP	-0.0004 * (AGE) ** 3 + 0.0104 * (AGE) ** 2 - 0.9005 * (AGE) + 100
Rutting Arterial Composite	100 * EXP(-0.0132 * AGE)
Rutting Arterial Flexible	100 * EXP(-0.0121 * AGE)
Rutting Collector Composite	100 * EXP(-0.0097 * AGE)
Rutting Collector Flexible	100 * EXP(-0.008 * AGE)
Rutting Interstate Composite	100 * EXP(-0.0121 * AGE)
Rutting Interstate Flexible	100 * EXP(-0.0121 * AGE)
Transverse Cracking Arterial JCP	100 - 0.6869 * AGE
Transverse Cracking Collector JCP	100 - 1.3712 * AGE

(continued)

Distress and Pavement Type, and Highway System	Performance Models
Transverse Cracking Interstate JCP	100 - 0.764 * AGE

The existing LADOTD family curve (Table 6) for rutting and Collector-ASP is shown in the following equation.

$$RTI = 100.\left[e^{-0.008(Age)}\right] \qquad (27)$$

where,
RTI = Rutting index;
Age = Pavement Age, year; and
100, -0.008 are regression coefficients.

The predicted RTI values using the existing LADOTD family curve as in equation (27) for the RTI was also plotted against the actual rutting index values as shown in Figure 19.

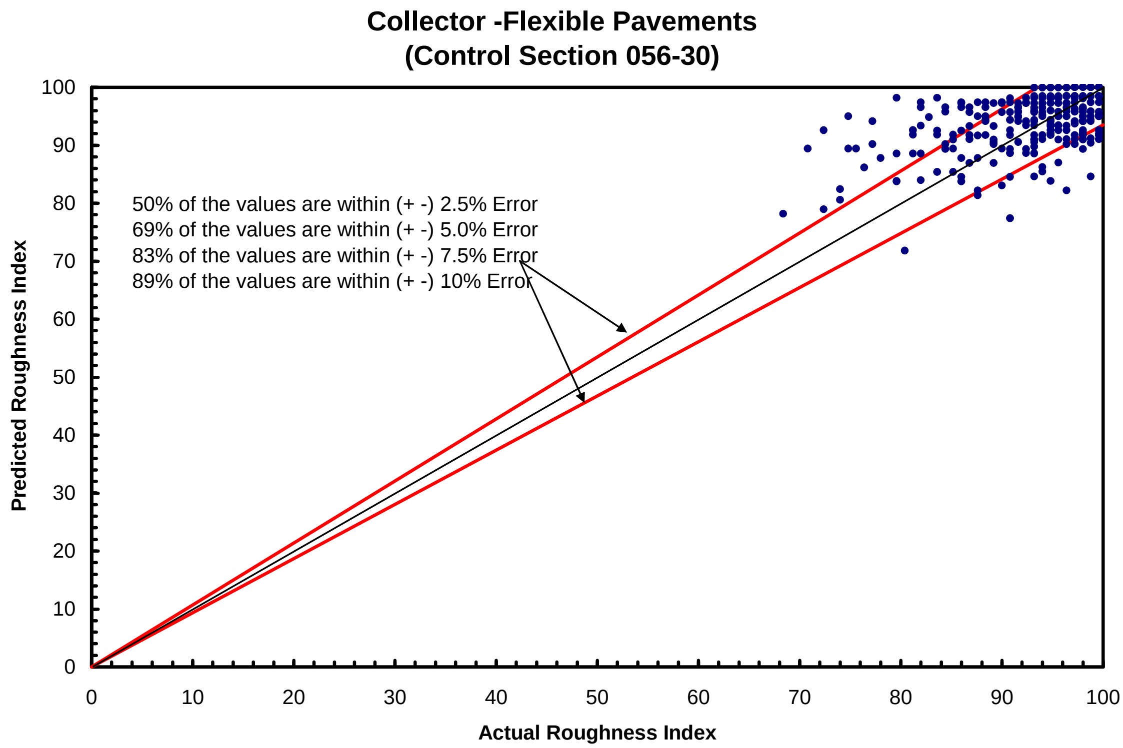


Figure 19

Predicted versus actual RTI values using the exiting LADOTD family curve

It can bee seen from the figure that the exiting model tends to overpredict the rutting index, in particular, for the RTI lower than 90. The error distribution between the predicted and actual

RTI values is also shown in Figure 20. The error analyses revealed that approximately 50, 69 and 83 percent of the data were within ± 2.5, ± 5, and ± 7.5 percent error, respectively. In addition, the error distribution is flatter and slightly skewed to the right. Flatter distribution represents a less precise model. On the other hand, the skewed distribution indicates a bias in the model suggesting that for the given control sections there are some over predicted values.

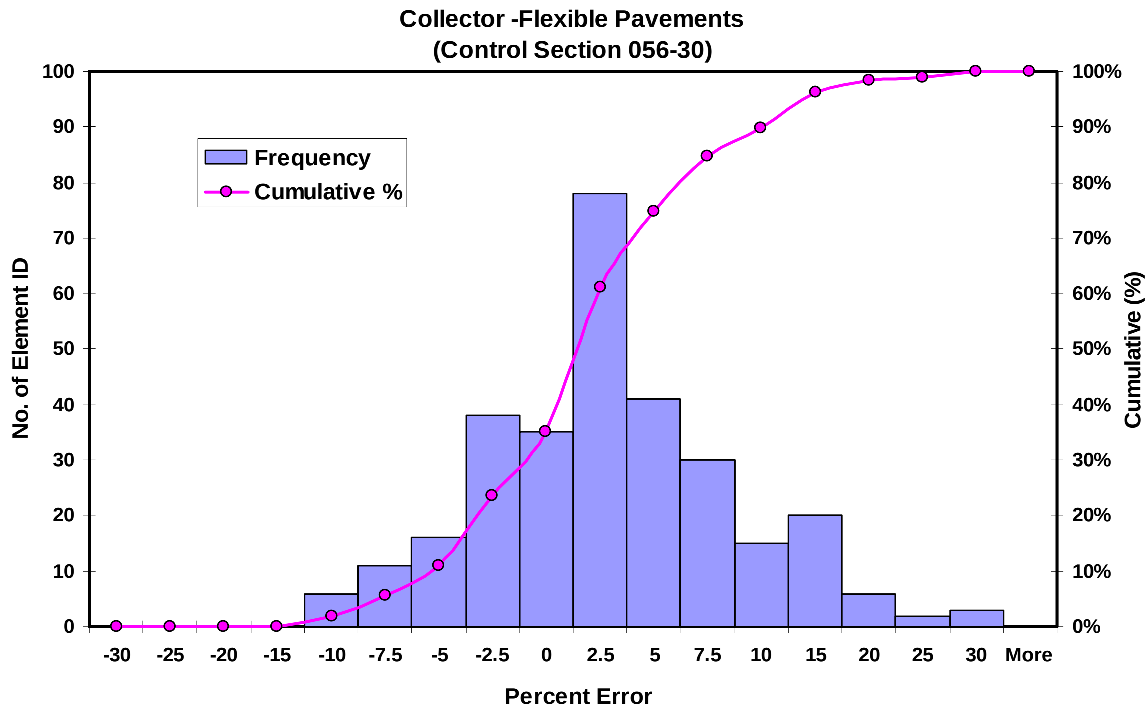


Figure 20

Percent error between actual and predicted RTI for the LADOTD family curve

Similarly, the existing LADOTD family curve for the RI for a collector flexible pavement is a polynomial function of the following form (Table 6).

$$RI = 0.0002.(Age)^3 - 0.0311.(Age)^2 - 0.5665.(Age) + 100 \qquad (28)$$

Using the above equation, the RI values were predicted for the randomly selected control sections of ASP-SHA. Figure 21 depicts the predicted versus actual values of RI using the LADOTD existing family curve. The visual inspection of the data indicates that the model exhibits a tighter band and even scatter of the data along the line of equality. Both properties are good indicators of an adequate model. On the other hand, the examination of error distribution plot (see Figure 22) implies that the distribution is flatter and skewed towards the right, exhibiting overpredictions. Furthermore, approximately 49, 65, 74, and 81 percent of the data is within ($\pm$) 2.5, 5, 7.5, and 10 percent error, respectively.

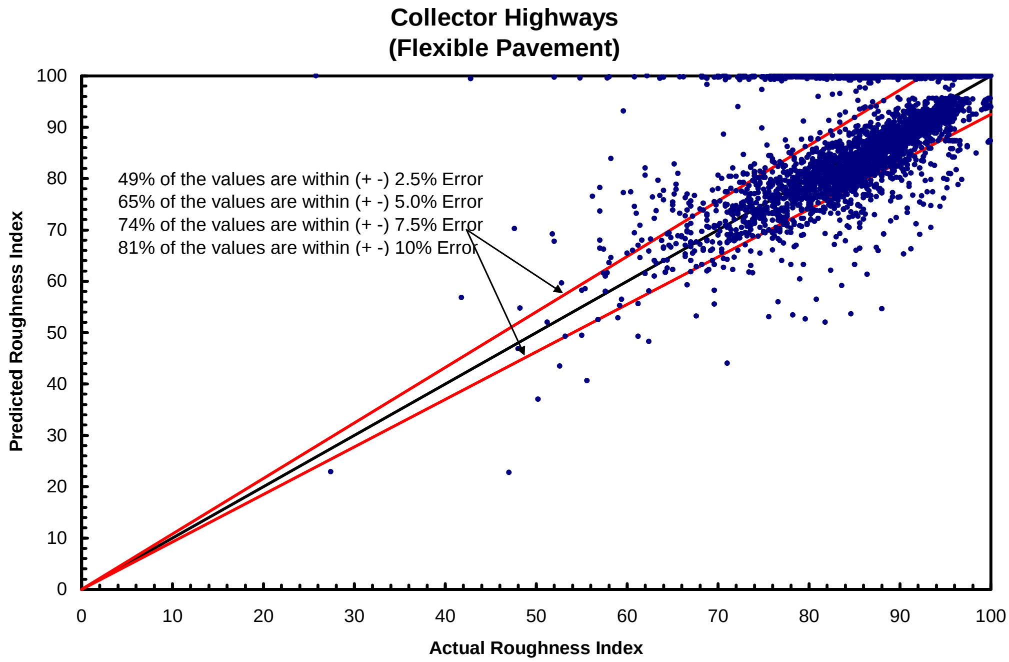


Figure 21
Predicted versus actual roughness index using the existing LADOTD family curve for roughness index of collector ASP

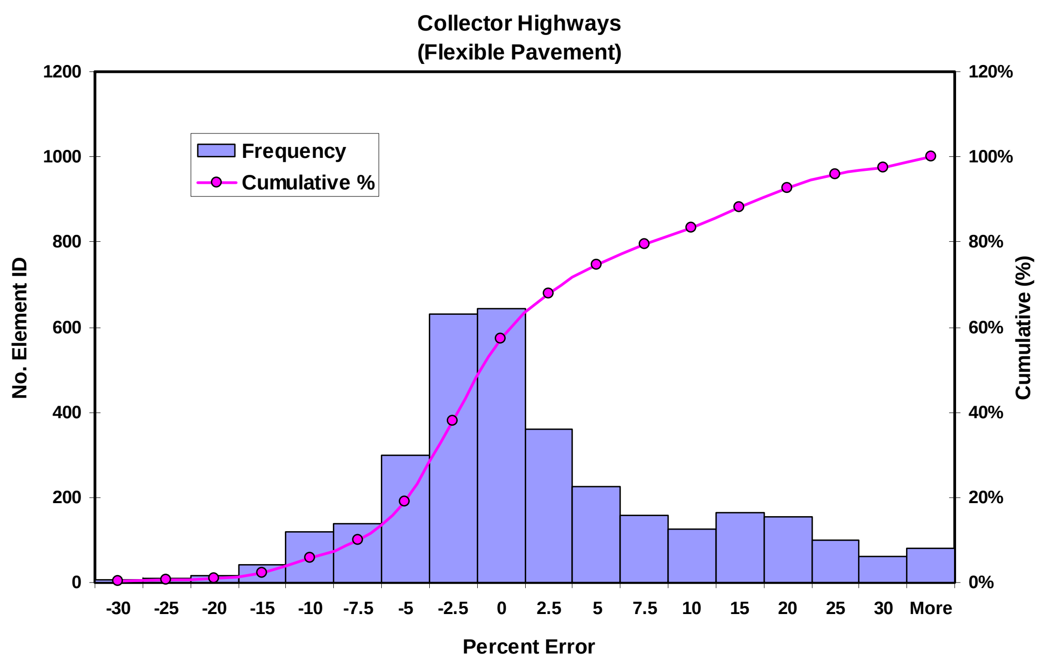


Figure 22
Distribution of percent error for predicted versus actual roughness index using the existing LADOTD family curve for roughness index of collector ASP

For the roughness index of an arterial flexible pavement highway, the LADOTD family curve is a polynomial function of the following form (Table 6):

$$RI = 0.0003.(Age)^3 - 0.0391.(Age)^2 - 0.7983.(Age) + 100 \quad (29)$$

The RI values were predicted using the above equation for randomly selected control sections. Figure 23 illustrates the predicted versus actual values of RI using the LADOTD existing family curve. The visual inspection of the data reveals that the model exhibits a tighter band but most of the values are below the line of equality. This observation implies that the model underpredicts the RI values. In addition, approximately 44, 60, 70, and 78 percent of the data are within (±) 2.5, 5, 7.5, and 10 percent error, respectively (Figure 24).

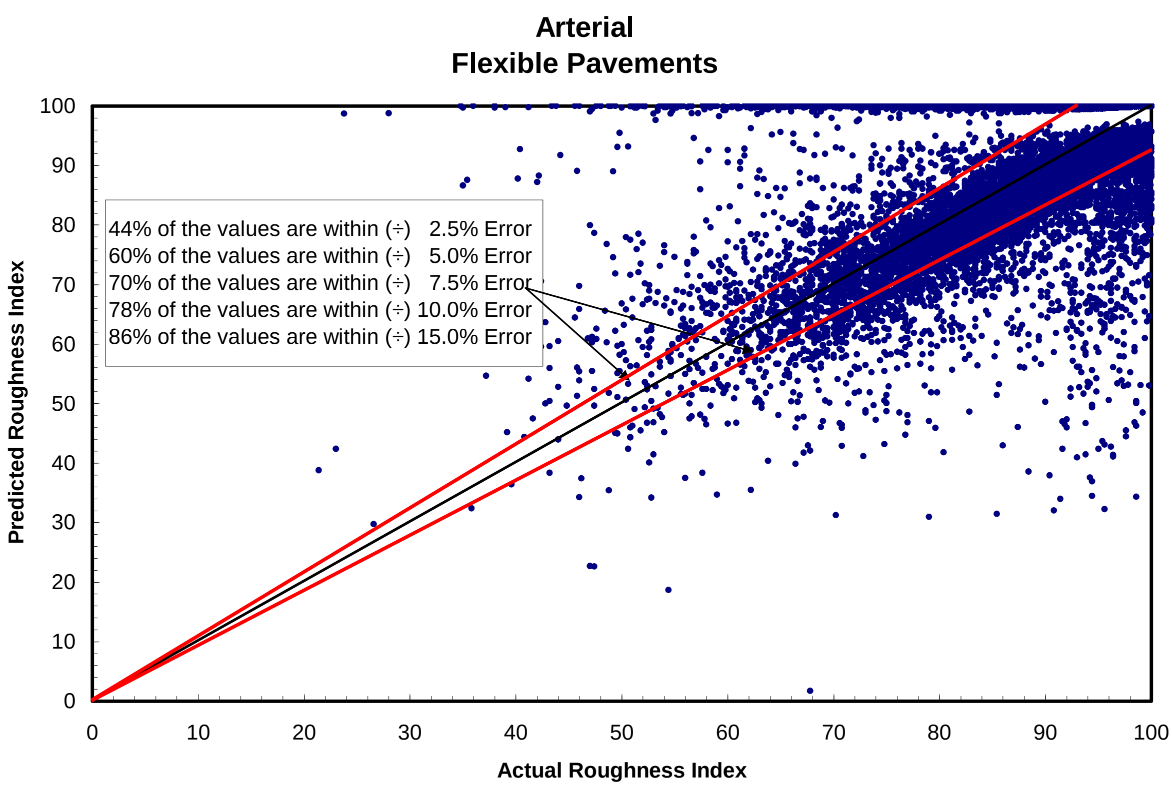


Figure 23

Predicted versus actual RI values based on LADOTD model-arterial

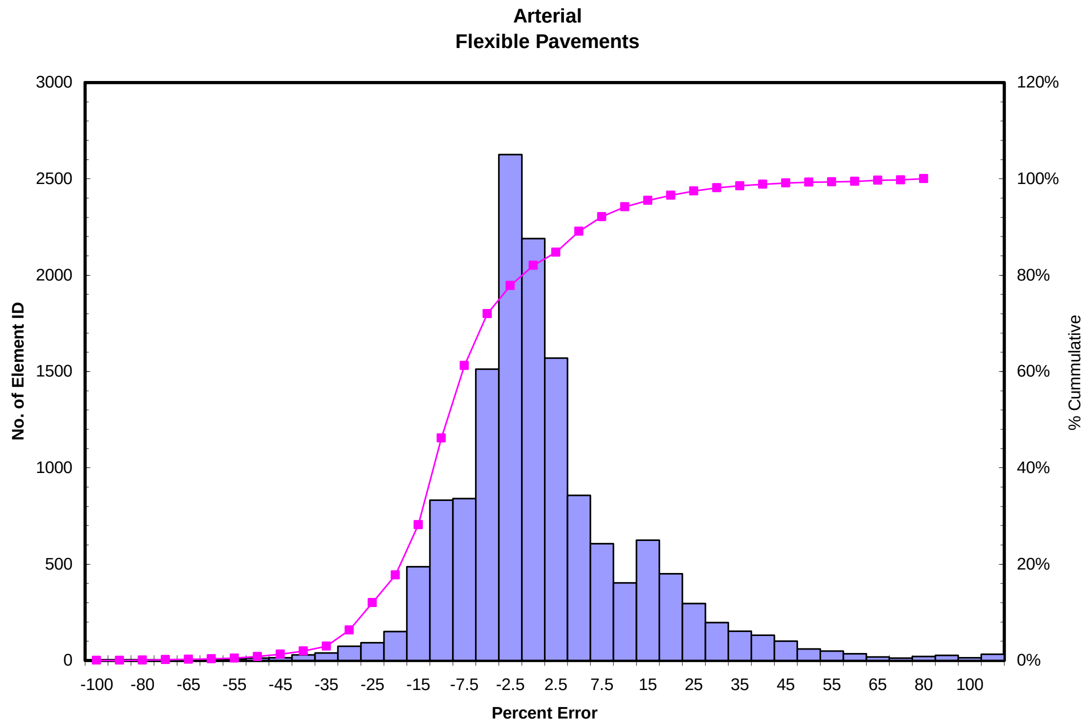


Figure 24

Distribution of percent error for predicted versus actual RI using the existing LADOTD family curve for RI of arterial ASP

Similar analyses were conducted for other LADOTD performance prediction models. Examples of some models are shown in Figures 25 through 28. Based on the review of the LADOTD models and the results of the analyses the following observations were made:

- The current pavement performance models either underpredict or overpredict various distress indices. This will affect the decision making regarding the appropriate time of maintenance and rehabilitation activities.
- The roughness index models of arterial composite, arterial JCP, collector composite, interstate JCP, and collector JCP are three degree polynomial functions. The leading coefficients are the order 10^{-16}, indicating that the first term has no statistical significance in the model. This clearly reflects deficiencies in the models.
- Most models are straight line functions, which are normally used when only the first few years of data are available. Such models provide good initial approximation of pavement condition but do not account for the higher rate of deterioration that occurs later due to the increase in pavement age.

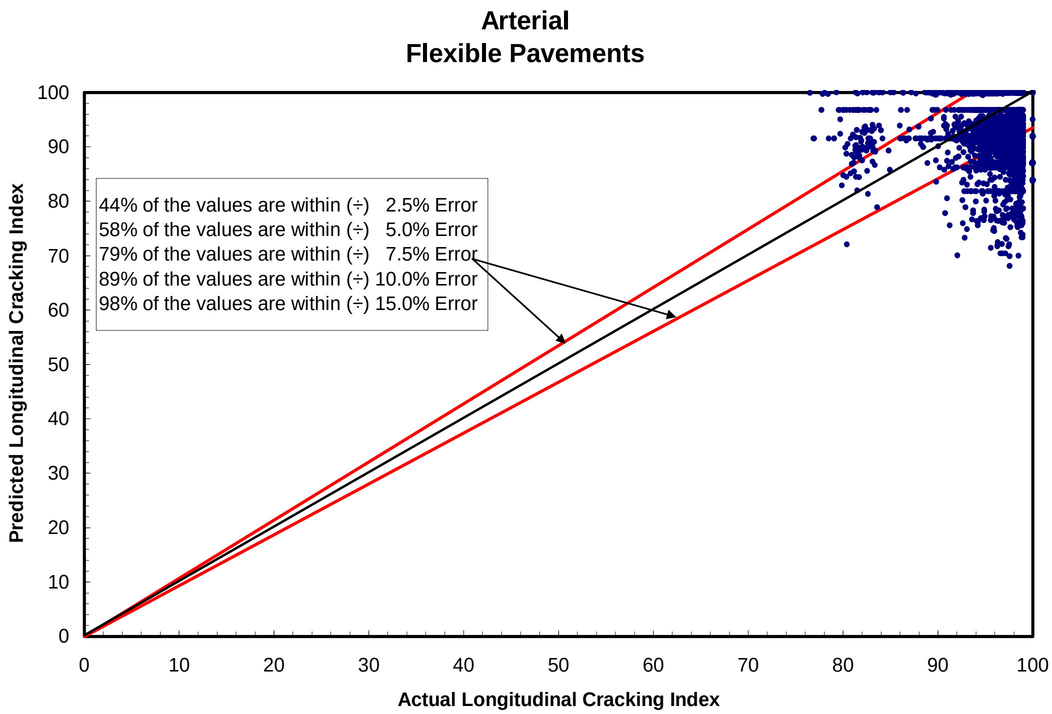


Figure 25
Predicted versus actual LCI values based on LADOTD model arterial ASP

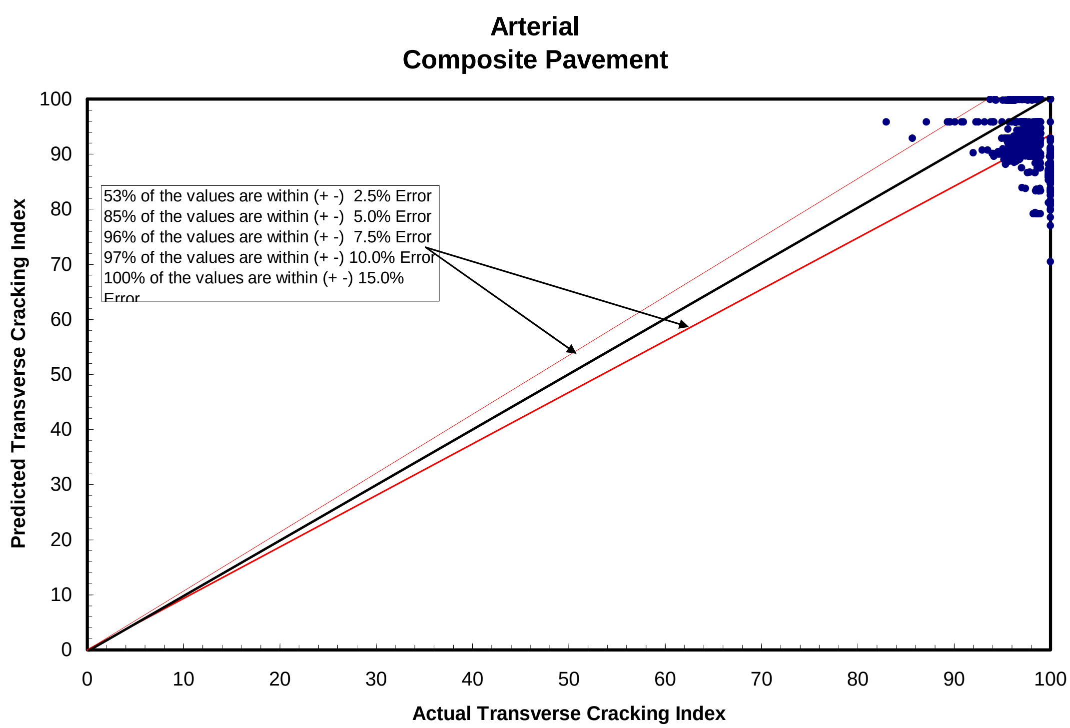


Figure 26
Predicted versus actual TCI values based on LADOTD model for arterial COM pavements

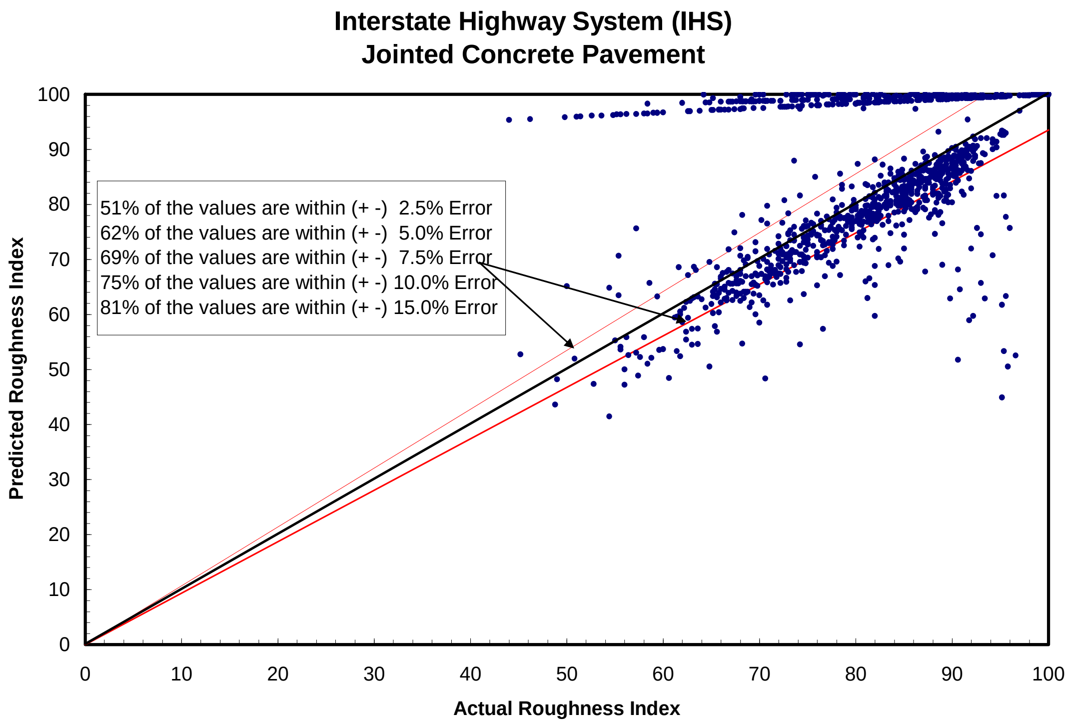


Figure 27
Predicted versus actual RI values based on LADOTD model for interstate JCP

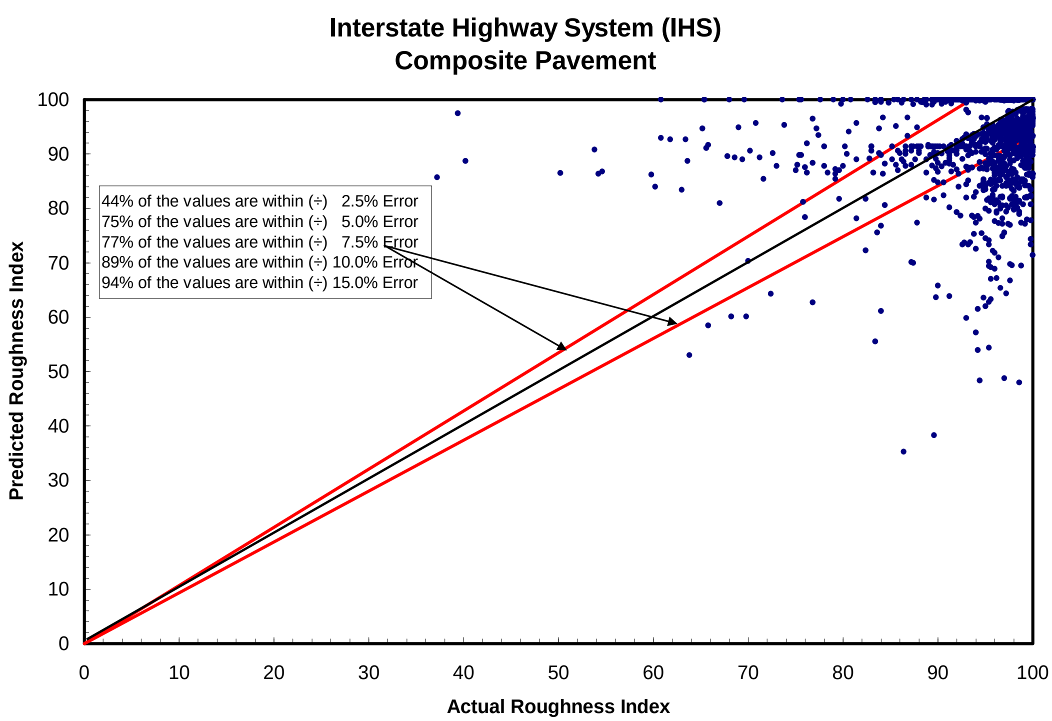


Figure 28
Predicted versus actual RI based on LADOTD model for interstate COM

Index Based Pavement Performance Models

Individual Pavement Performance Models

Recall that three regression models were developed for each control section namely; upper, middle and lower one-third percentile models. Furthermore, the models were for each highway classification, pavement type and distress type. Example of one such model for a rutting index of ASP-SHS and control section 056-30 is as follows.

$$RTI = 100 - b(SA)^{a} \qquad (30)$$

where,
RTI = Rutting index;
SA = Surface age, year;
b = 0.051, 0.087, and 0.304 for upper, middle, and lower models, respectively; and
a = 1.564, 1.774, and 1.584 for upper, middle, and lower models, respectively.

The predicted versus actual RTI values for the three percentile models are shown in Figure 29. It is evident from the figure that 89 and 95 percent of the data is within ± 5 and ± 7.5 error, respectively. This indicates that the developed models are satisfactory.

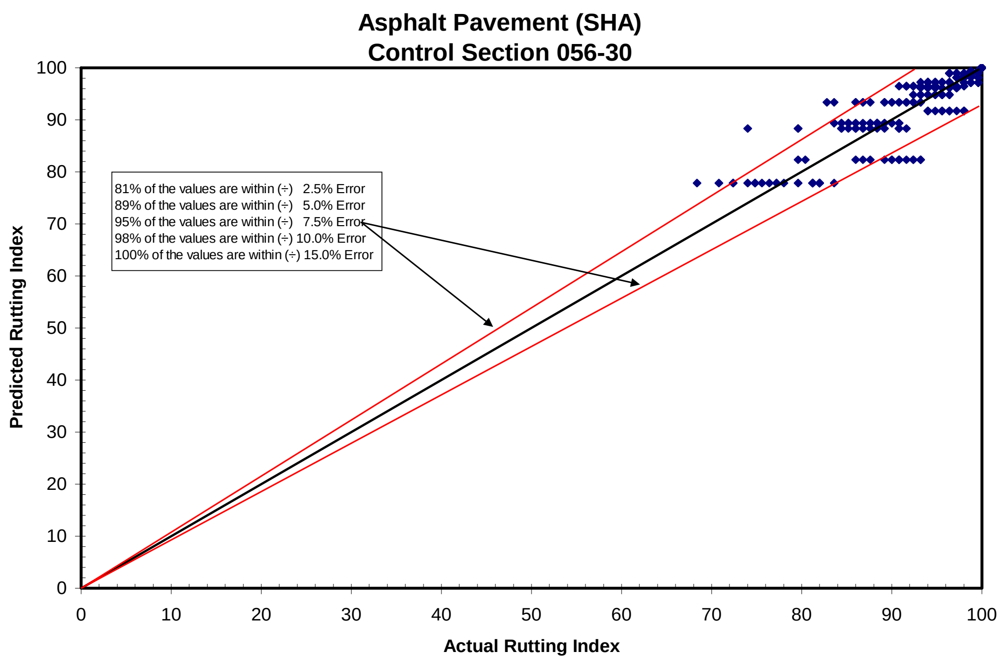


Figure 29
Predicted versus actual RTI values using three percentile models

As reported earlier, the regression analyses were performed for all the control sections and numerous models were established. The examples of such analyses and predicted versus actual values are shown in Figures 30 through 49, and the results are summarized in Appendix B.

The individual models developed for each control section exhibited good prediction capabilities. These models should be used for project level PMS analysis. It should be noted that the project level PMS involves:

1. Engineering analysis and various design options or each feasible rehabilitation alternatives and their estimated costs
2. Optimization lists of the various designs of all projects relative to a set of pre-established criteria, goals, and objectives of the Department

The individual models will facilitate final selection of maintenance and rehabilitation alternatives based on the established LADOTD trigger/threshold index values for various distress types. Moreover, the individual models for each control section can also aid in estimating the life of pavement section after being successively rehabilitated.

The individual control section models may need a gradual and steady implementation plan for LADOTD because the application of these models may require initial preparation and formatting of the PMS data set along with some computer logic and scheme of analysis for their application.

Continuously Reinforced Concrete Pavement (CRC)
Interstate Highway System

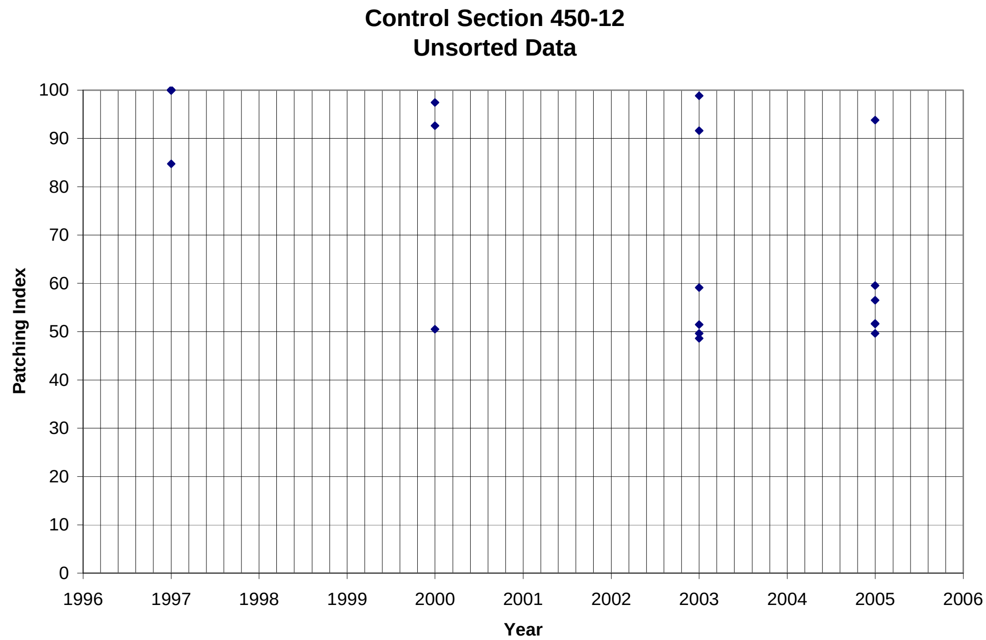


Figure 30

Patching index data based on data collection year for CRC-IHS

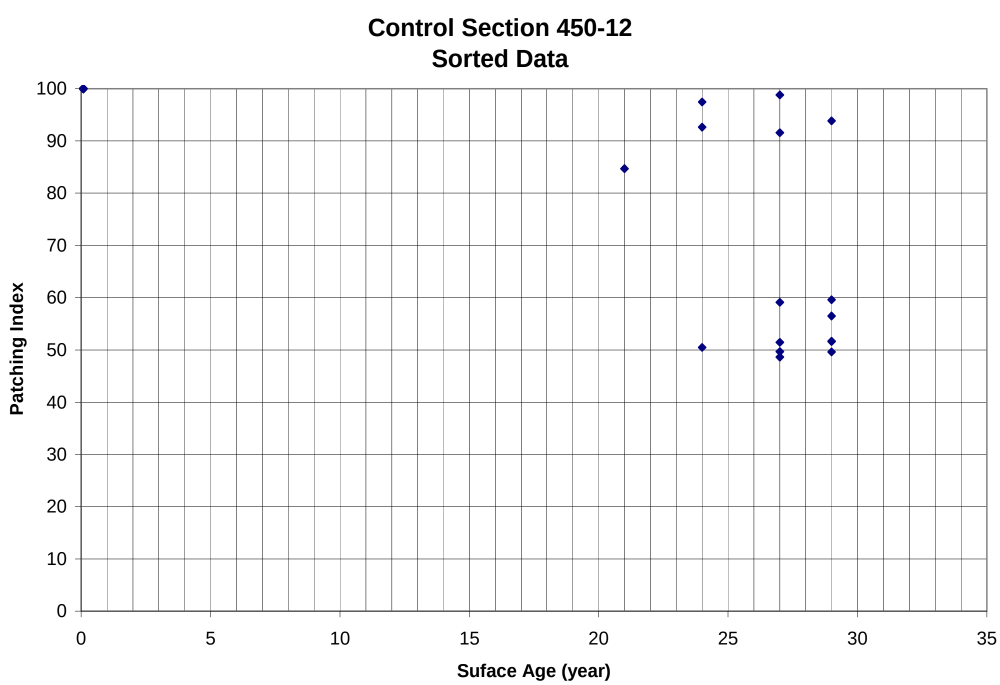
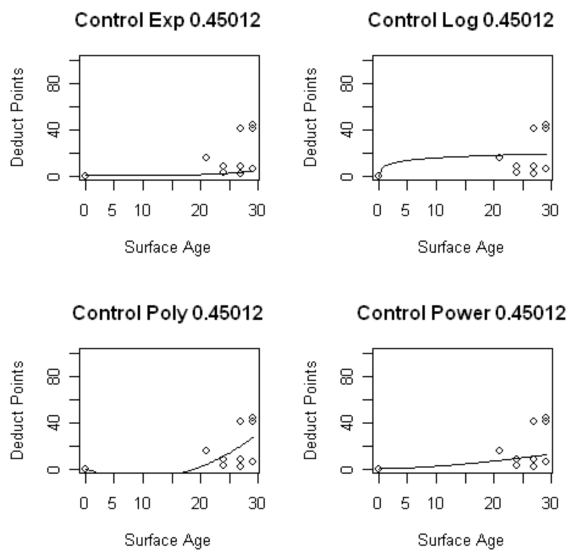


Figure 31

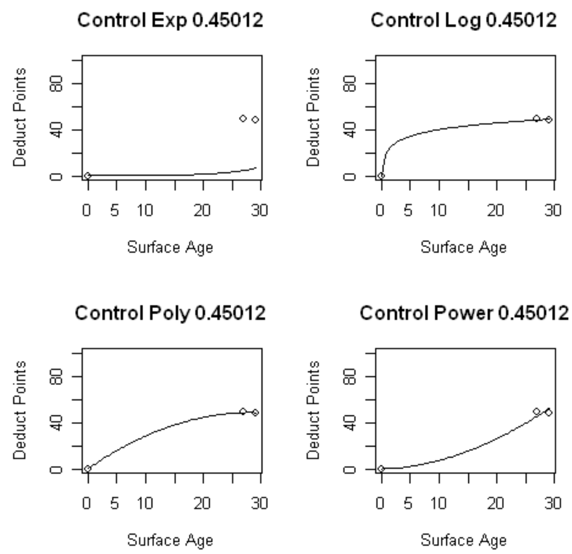
Shifted patching index data based on historical resurface year for CRC-IHS

(control section 450-12)

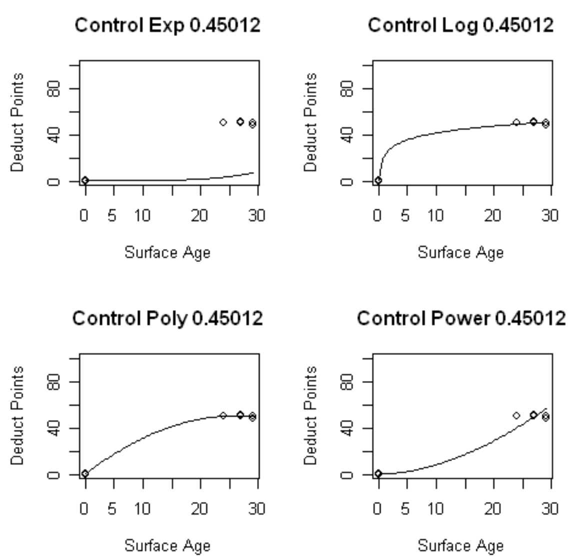
(a) Upper Model



(b) Middle Model



(c) Lower Model



Final Models

$$PI_{upper} = 100 - 0.054 \cdot SA^{1.606}$$

$$PI_{middle} = 100 - 0.101 \cdot SA^{1.853}$$

$$PI_{lower} = 100 - 0.128 \cdot SA^{1.807}$$

Legends

Exp:	Exponential Function
Log:	Logarithmic Function
Ploy:	Polynomial Function
Power:	Power Function

Figure 32
Typical output charts of regression models using "R" program for patching index of CRC-IHS (control section 450-12)

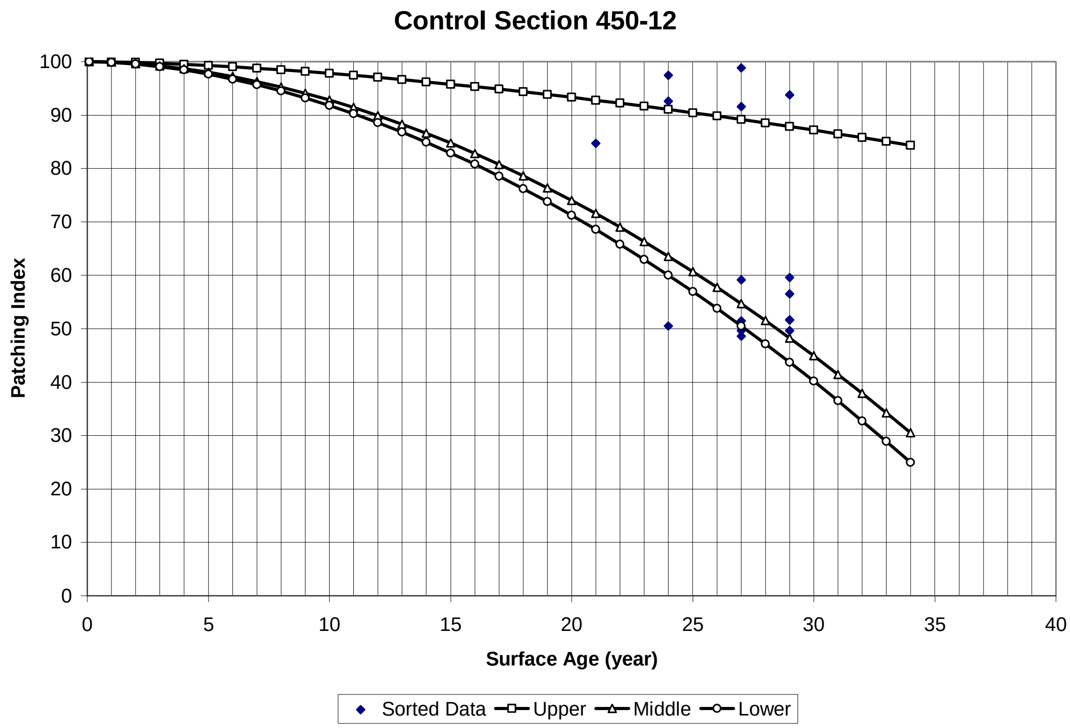


Figure 33
Typical plot of patching index showing all the 1/3rd percentile models for CRC-IHS

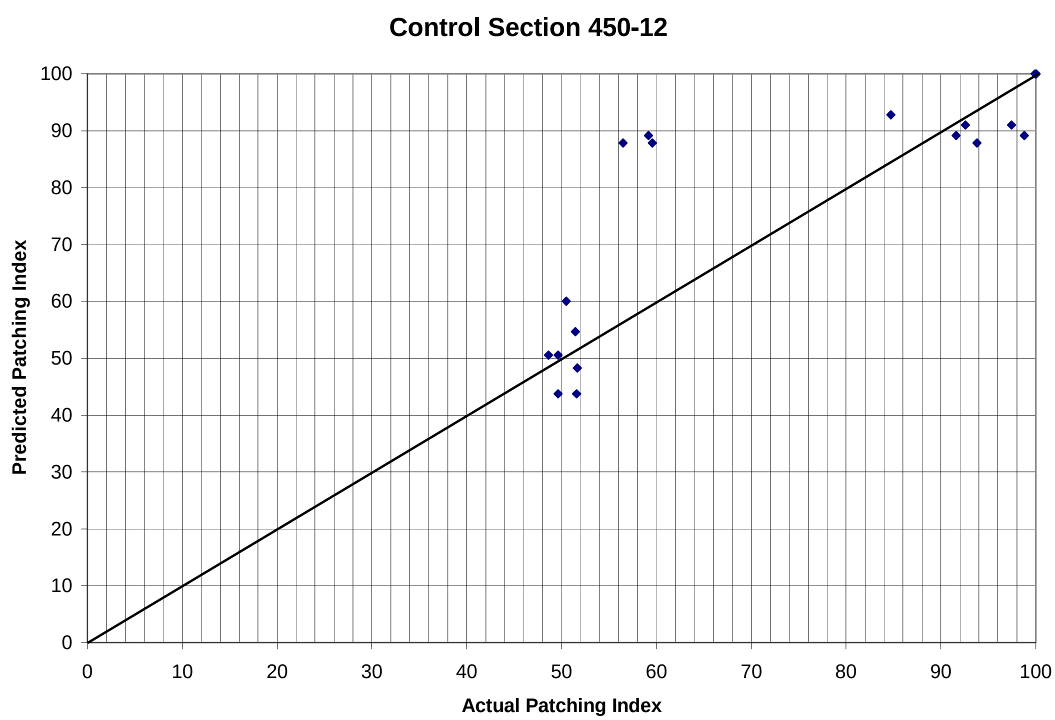


Figure 34
Predicted versus actual values for all the 1/3rd percentile models for patching index of CRC pavement-IHS

Composite Pavement (COM)
State Highway System

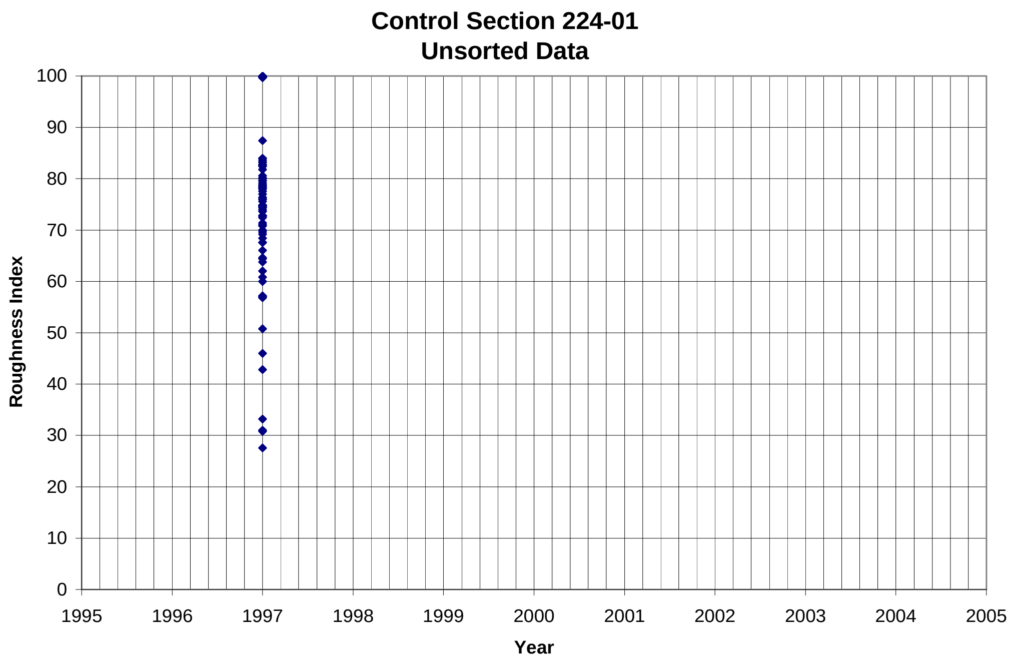


Figure 35
Roughness index data based on data collection year for COM-SHS

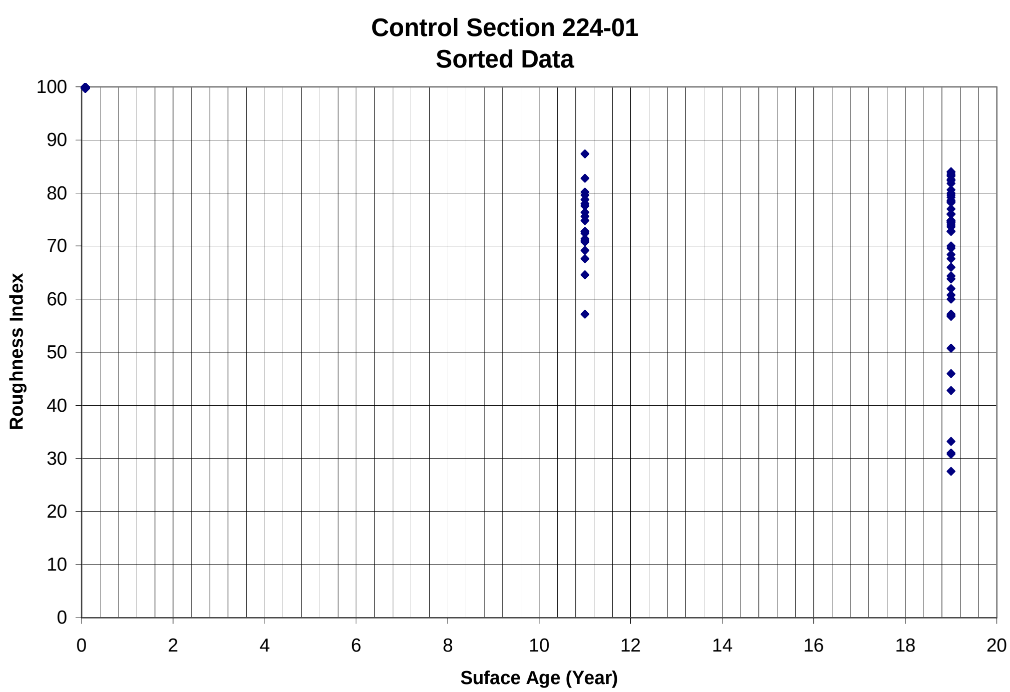
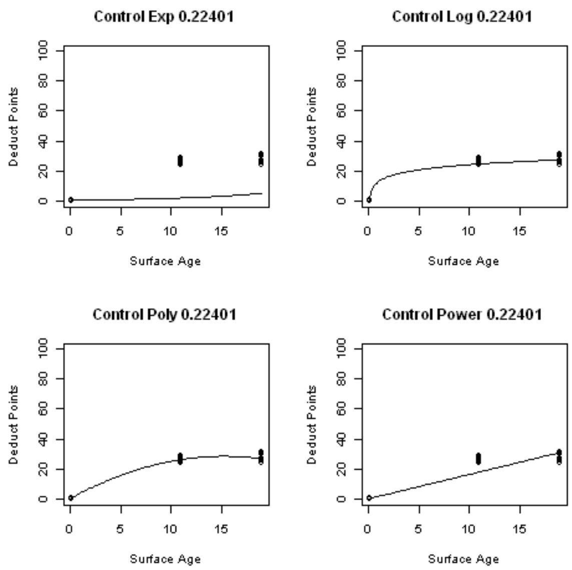
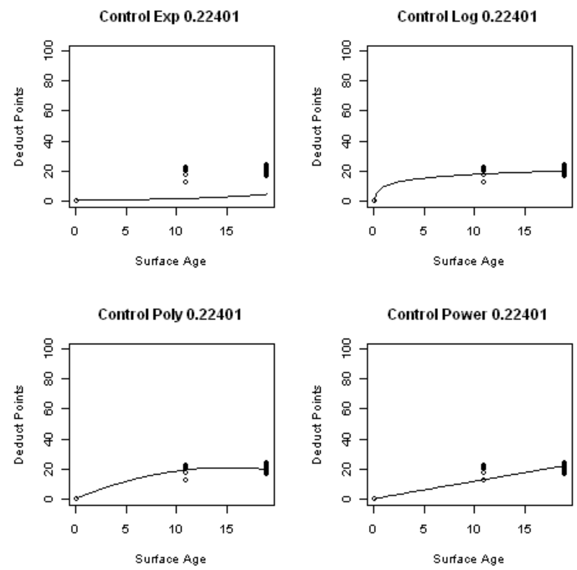


Figure 36
Shifted roughness index data based on historical resurface year for COM-SHS (control section 224-01)

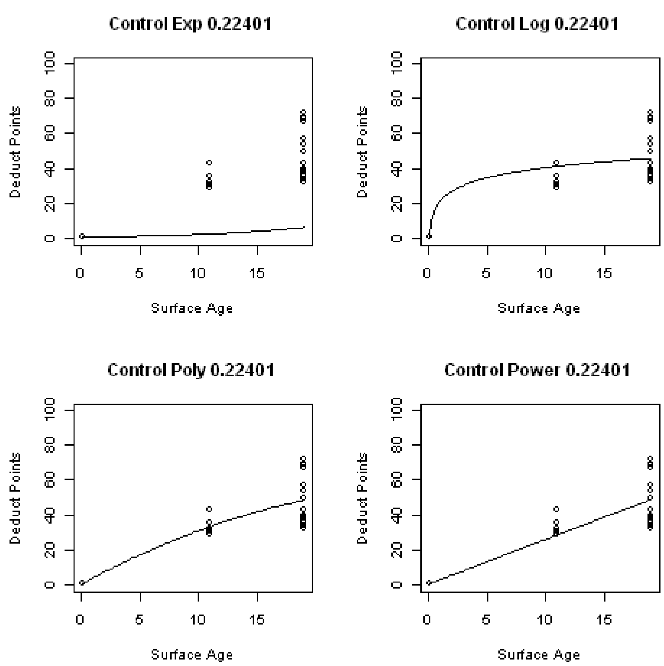
(a) Upper Model



(b) Middle Model



(c) Lower Model



Final Models

$$PI_{upper} = 100 - 1.192 \cdot SA^{0.993}$$

$$PI_{middle} = 100 - 1.609 \cdot SA^{1.004}$$

$$PI_{lower} = 100 - 2.647.SA^{0.990}$$

Legends

Exp:	Exponential Function
Log:	Logarithmic Function
Ploy:	Polynomial Function
Power:	Power Function

Figure 37
Typical output charts of regression models using “R” program for RI of COM-SHS (control section 224-01)

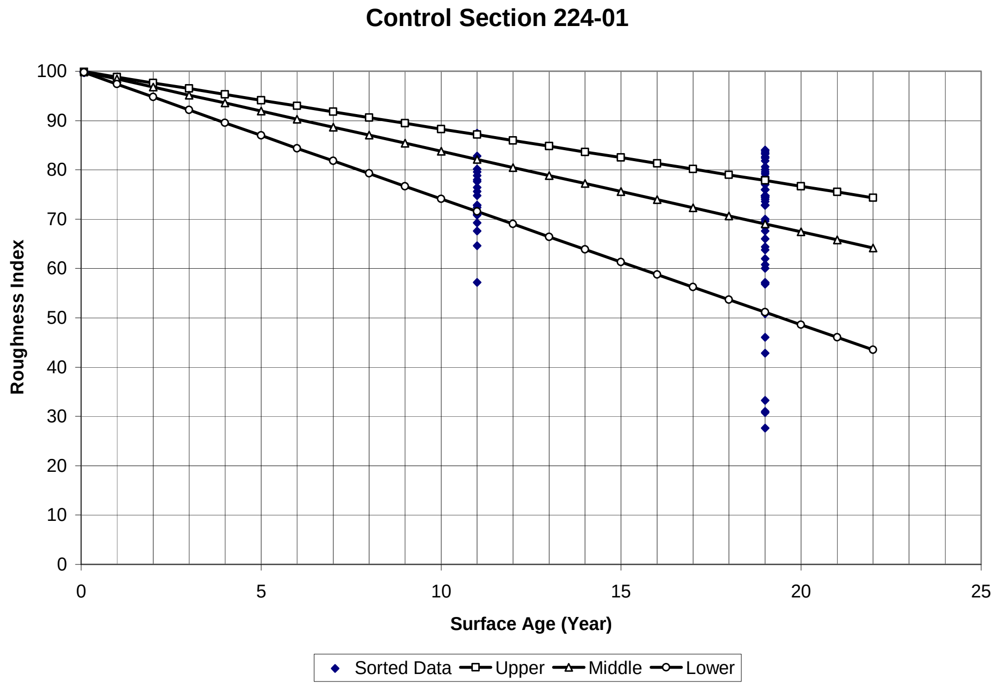


Figure 38
Typical plot of roughness index showing all the 1/3rd percentile models for COM-SHS

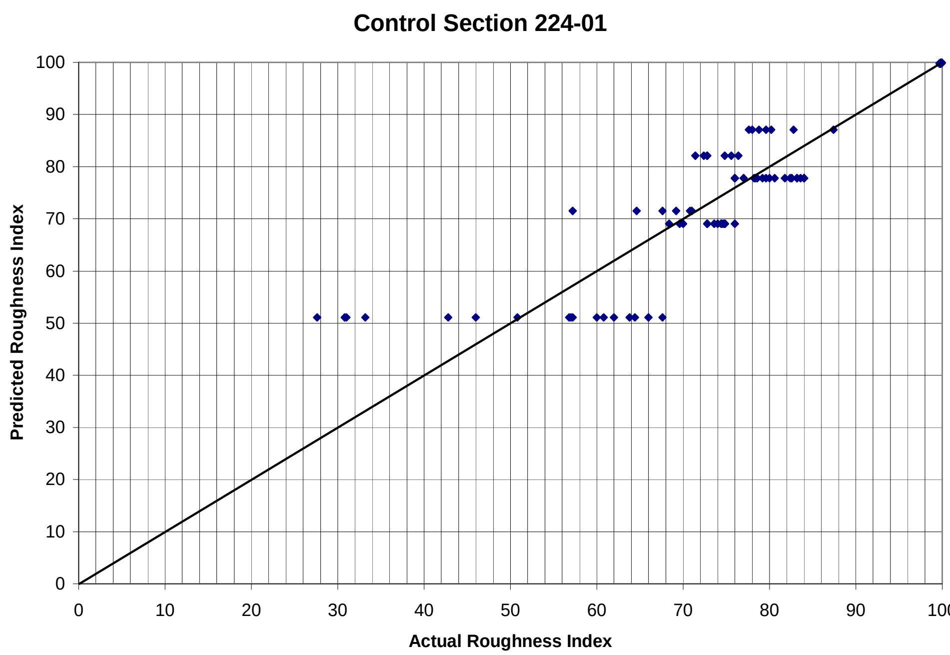


Figure 39
Predicted versus actual values for all the three 1/3rd percentile models for RI of COM-SHS

Flexible Pavement (ASP)
State Highway System

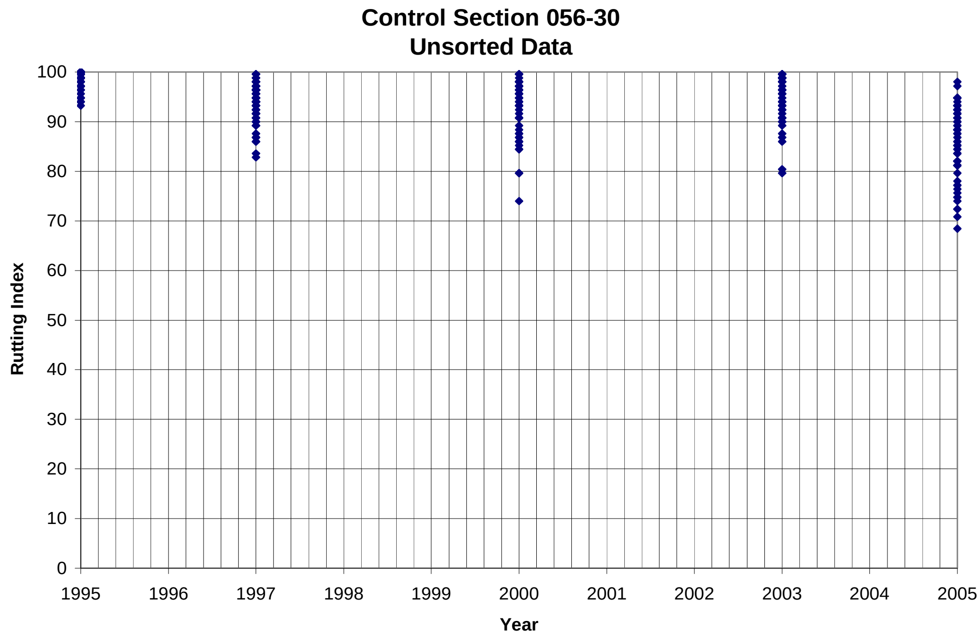


Figure 40
Rutting index data based on data collection year for ASP-SHS

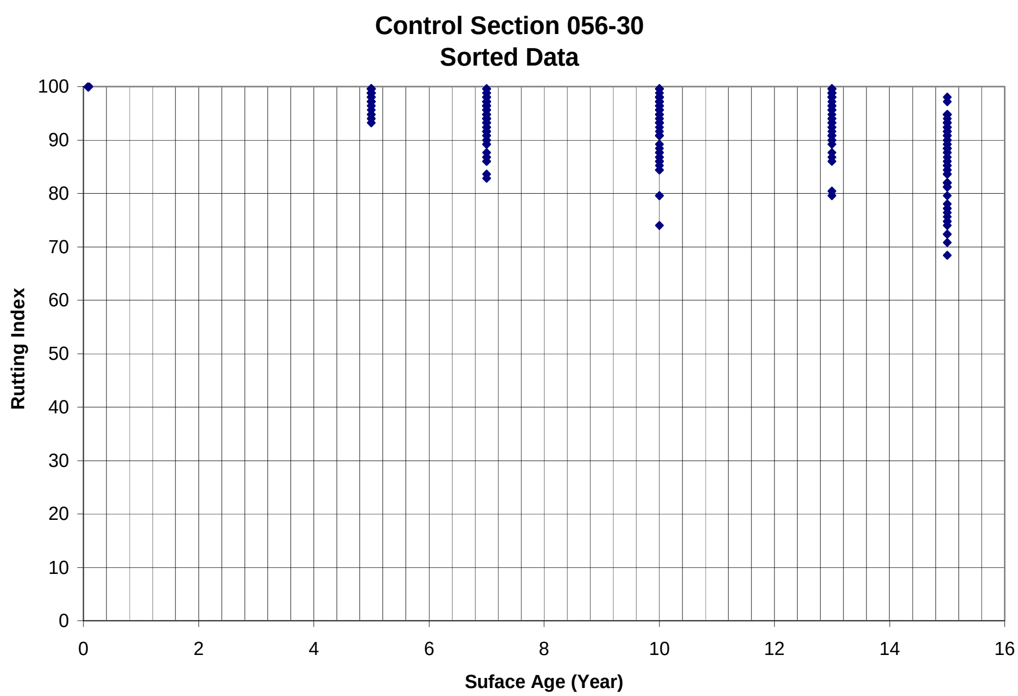
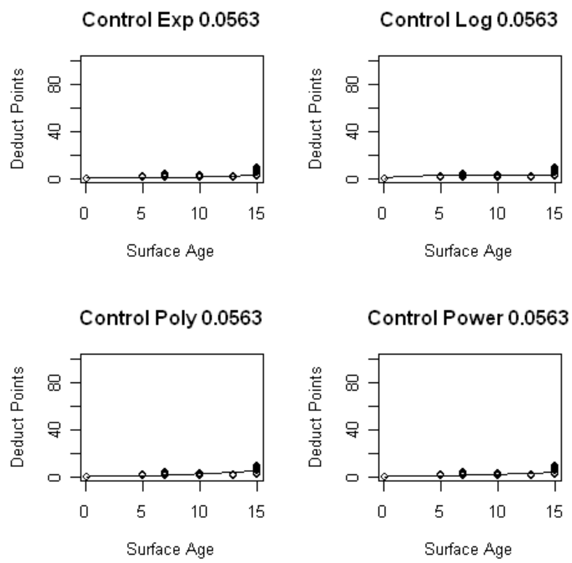


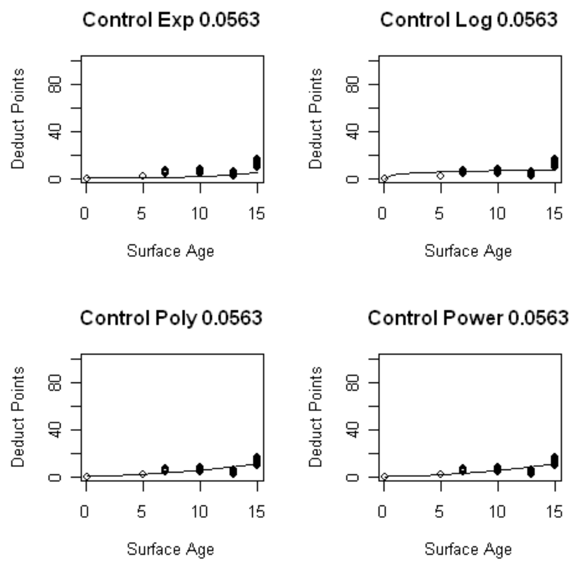
Figure 41
Shifted rutting index data based on historical resurface year for ASP-SHS

(control section 056-30)

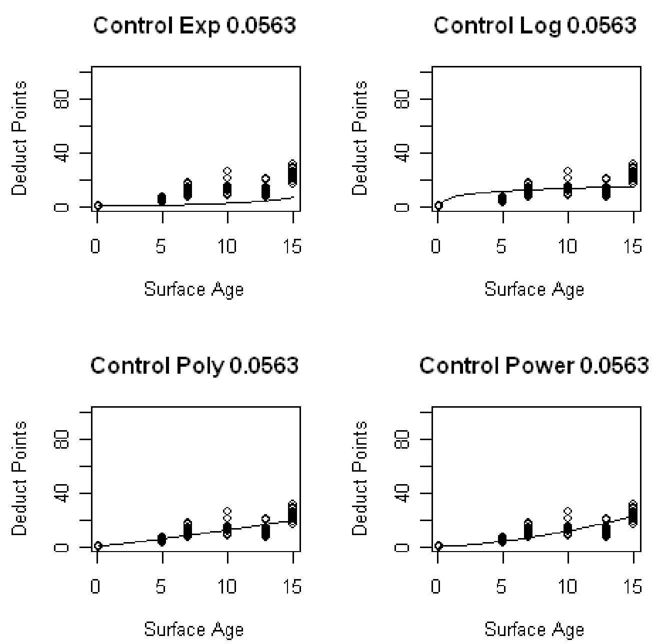
(a) Upper Model



(b) Middle Model



(c) Lower Model



Final Models

$$PI_{upper} = 100 - 0.051 \cdot SA^{1.564}$$

$$PI_{middle} = 100 - 0.087 \cdot SA^{1.774}$$

$$PI_{lower} = 100 - 0.304 . SA^{1.584}$$

Legends

Exp:	Exponential Function
Log:	Logarithmic Function
Ploy:	Polynomial Function
Power:	Power Function

Figure 42
Typical output charts of regression models using "R" program for rutting Index of ASP-SHS (control section 056-30)

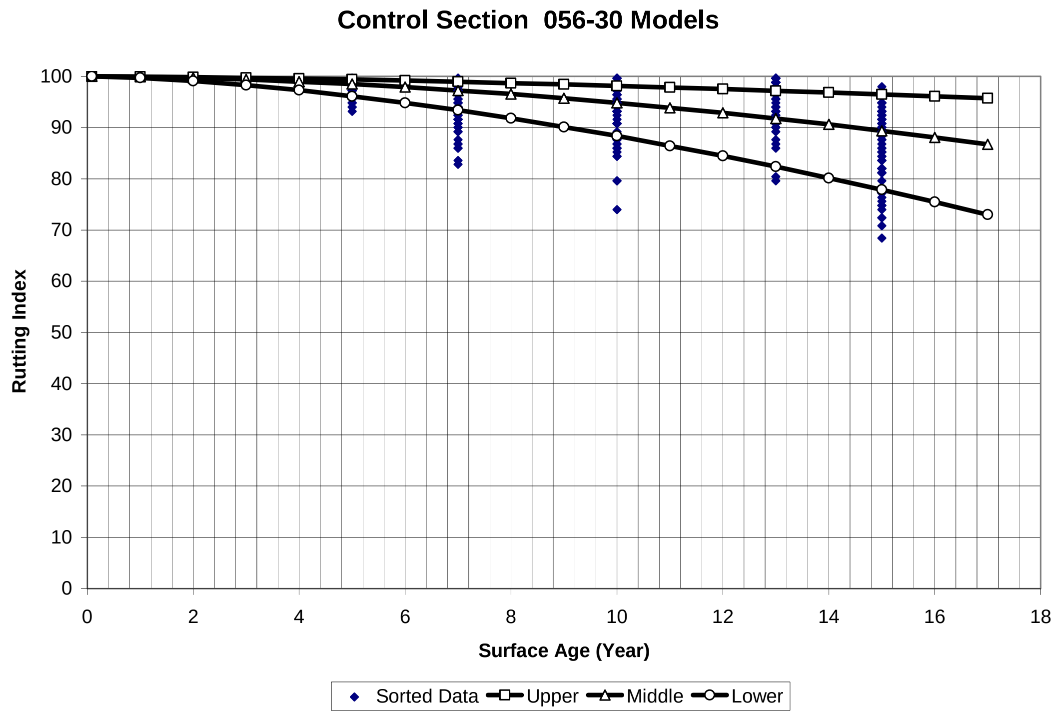


Figure 43
Typical plot of rutting index showing all the three 1/3rd percentile models for ASP-SHS

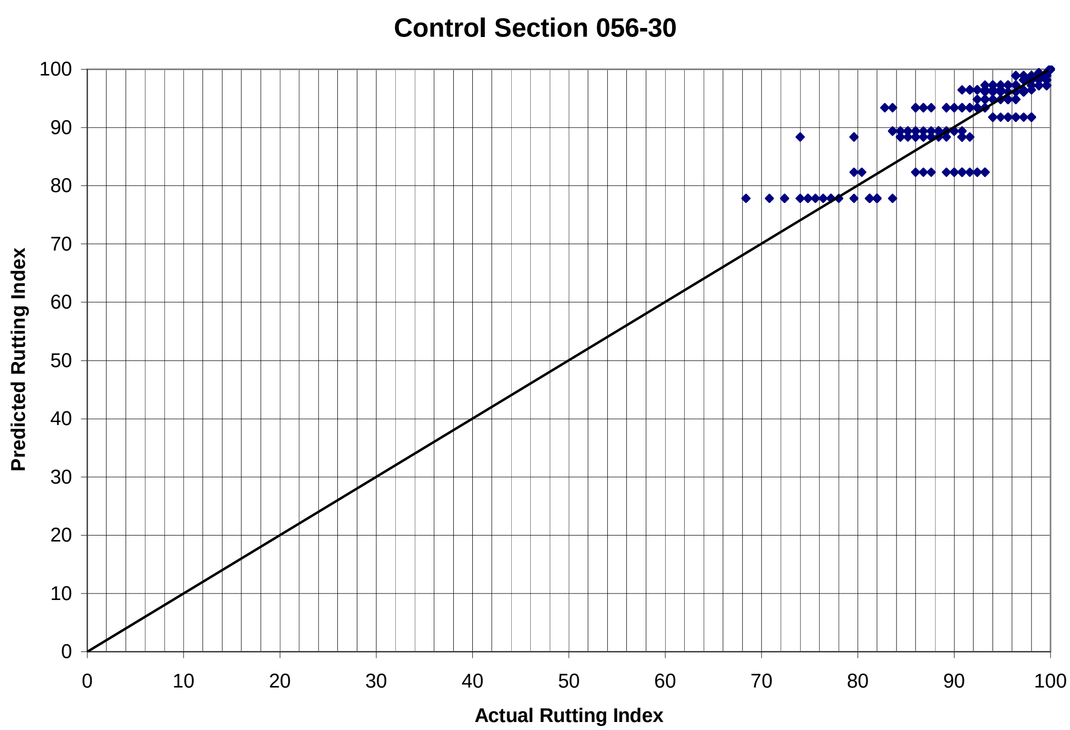


Figure 44
Predicted versus actual values for all the three 1/3rd percentile models for RTI of ASP-SHS

Jointed Plain Concrete Pavement (JPC)

National Highway System

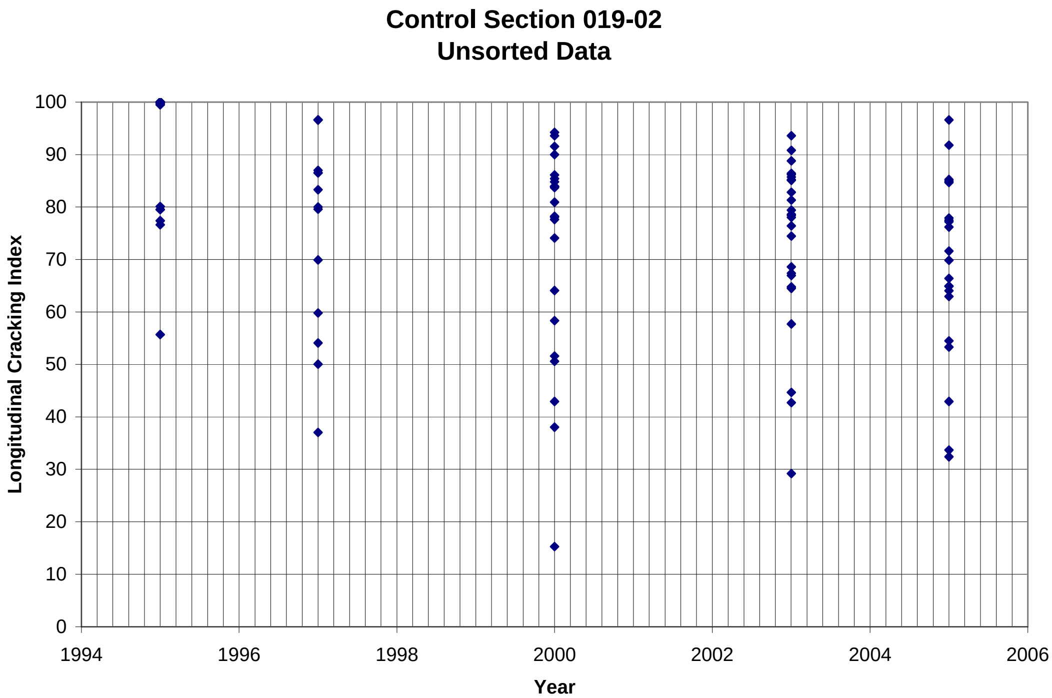


Figure 45
LI based on data collection year for JPC-NHS

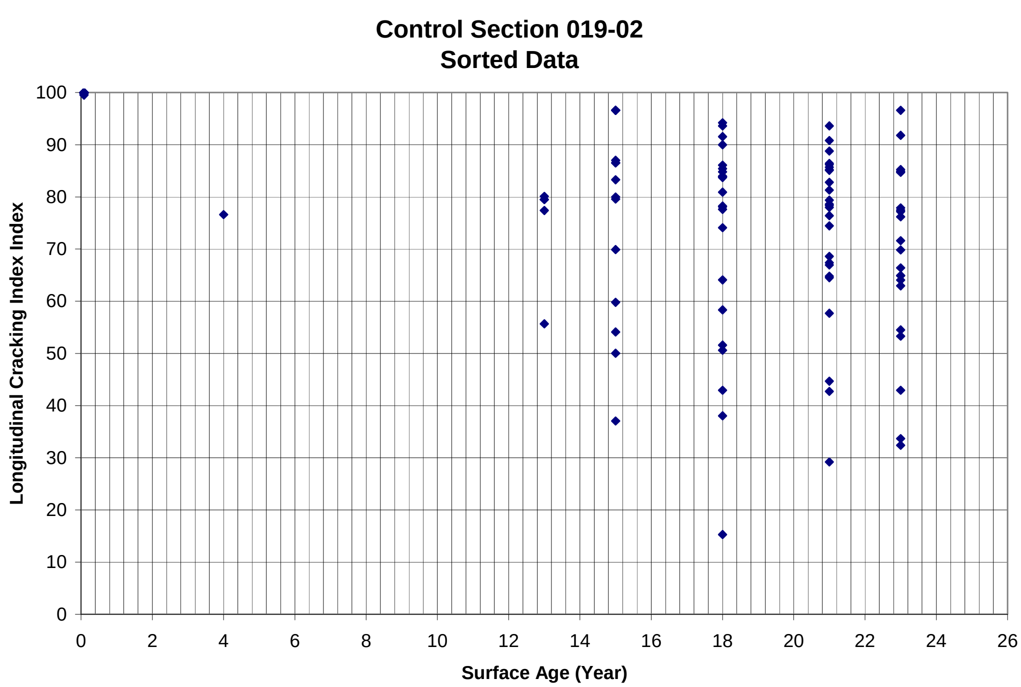
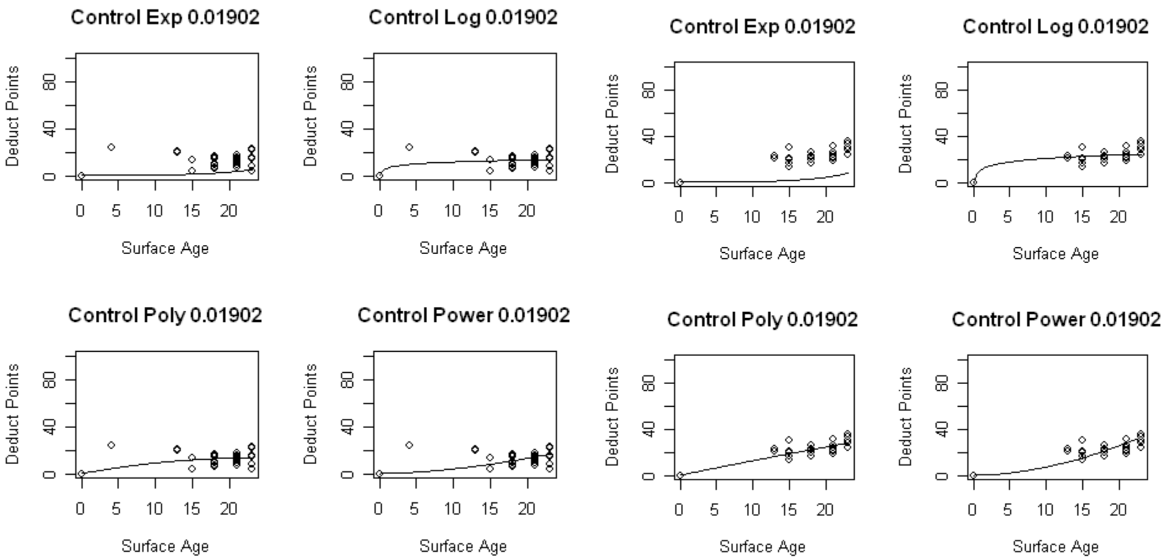


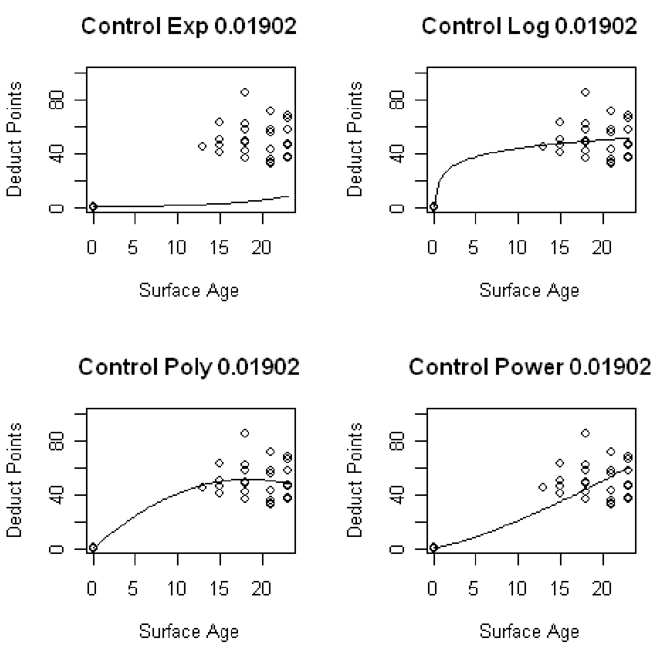
Figure 46
Shifted LI based on historical resurface year for JPC-NHS

Control Section 019-02

(a) Upper Model **(b) Middle Model**



(c) Lower Model



Final Models

$$PI_{upper} = 100 - 0.078 \cdot SA^{1.705}$$

$$PI_{middle} = 100 - 0.100 \cdot SA^{1.846}$$

$$PI_{lower} = 100 - 1.086 \cdot SA^{1.278}$$

Legends

Exp:	Exponential Function
Log:	Logarithmic Function
Ploy:	Polynomial Function
Power:	Power Function

Figure 47
Typical output charts of regression models using "R" program for LI of JCP-NHS (control section 019-02)

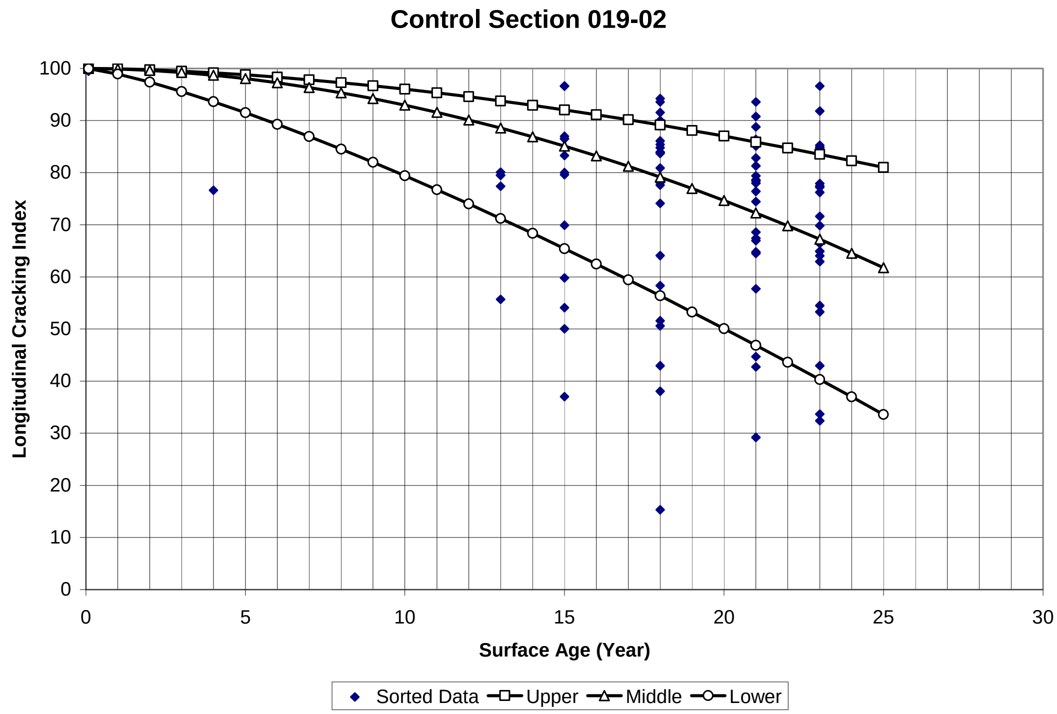


Figure 48
Typical plot of LI showing all the three 1/3rd percentile models for JCP-NHS

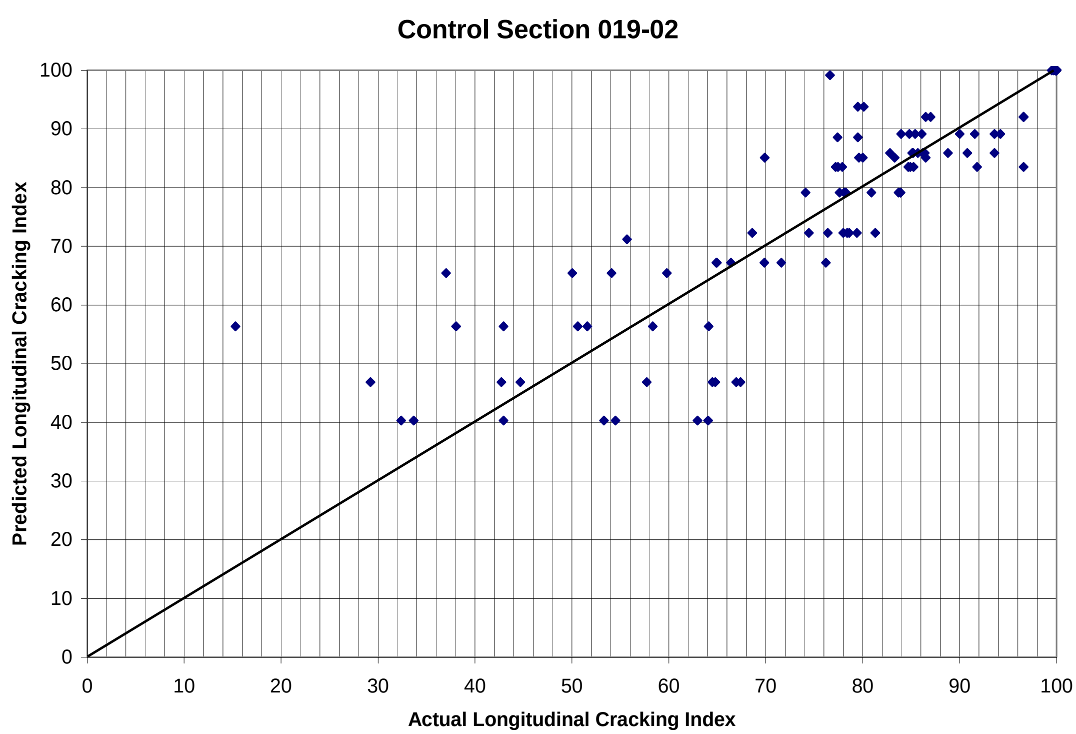


Figure 49
Predicted versus actual values for all the three 1/3rd percentile models for LI of JCP-NHS

Consolidated Pavement Performance Models

Based on the pavement rate of deterioration the models developed for numerous control sections were consolidated to reduce the total number of models. The consolidation technique has been reported in detail in the Methodology section of this report. A few typical examples of such analyses are also shown in Figures 50 through 57 and associated control sections are listed in Tables 7 through 9.

After the model consolidation, the index data for various control sections were randomly selected and predicted using the respective consolidated models. The list of randomly selected control sections for the roughness index of ASP SHS is shown in Table 10. It should be noted these randomly selected control sections were the same as used for existing LADOTD models for Collector ASP (Figure 22). The predicted and actual RI values were also plotted and are shown in Figure 54. The data in the figure indicate that approximately 57, 73, 82, and 91 percent of the data is within (±) 2.5, 5, 7.5, and 10 percent error, respectively. It was also found that the distribution of the error between the predicted and actual values was random in nature, which is one of the important assumptions of regression analyses (see Figure 55). The results of all the consolidated models are summarized in Appendix C.

The comparison of the two error distributions and predicted versus actual values shown in Figures 21, 22, 54, and 55 clearly indicates that the consolidated models provide better predictions of RI values. It must be noted that the existing family curves are applied to the current index value to predict the future condition of the pavement sections. If similar techniques were utilized for the consolidated models, the predictions can be further improved as shown in the Figures 56 and 57. Up to 6 percent improvements were observed considering the current condition of the pavement sections.

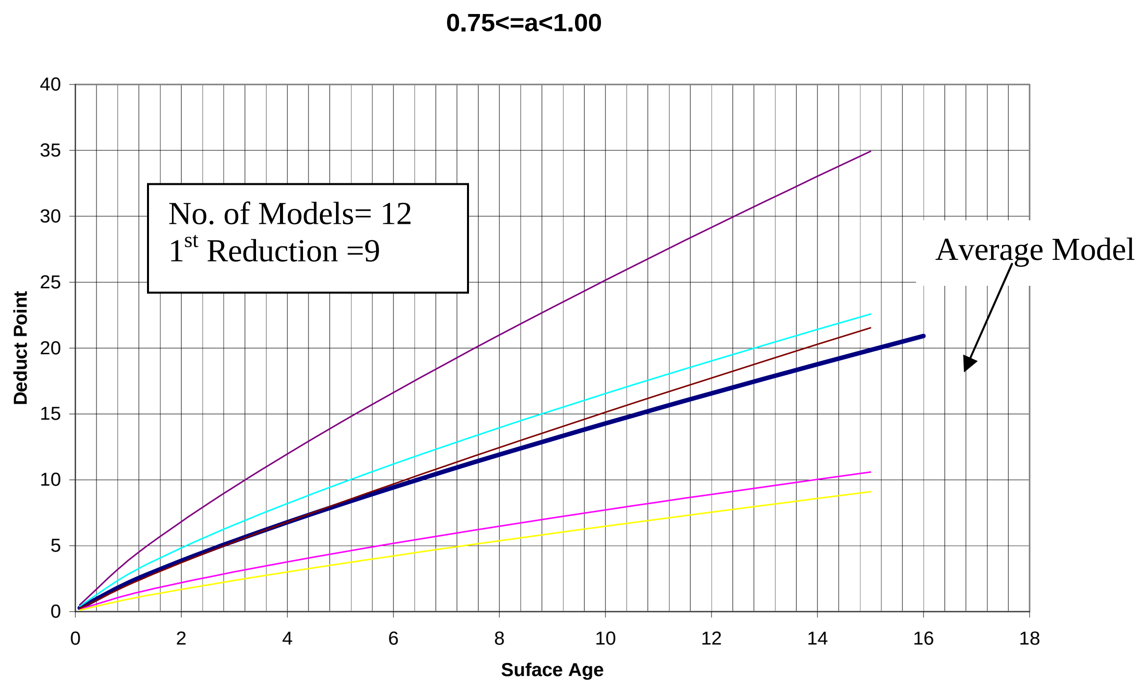


Figure 50

Initial model consolidation for RI model of ASP-IHS

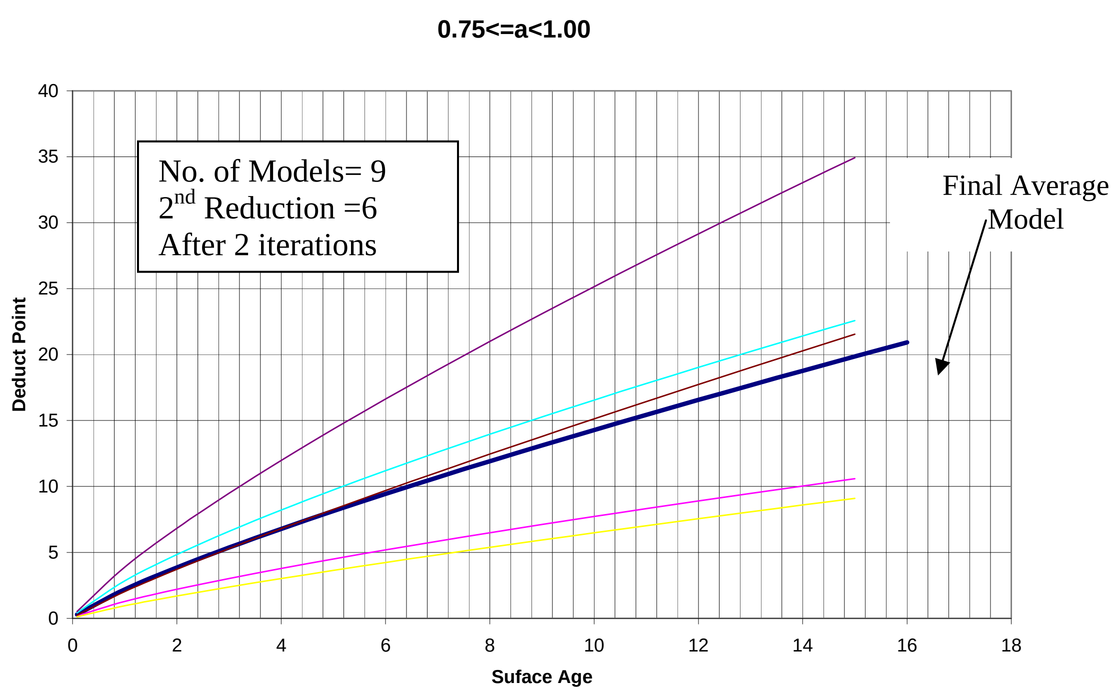


Figure 51

Final model consolidation for RI model of ASP-IHS

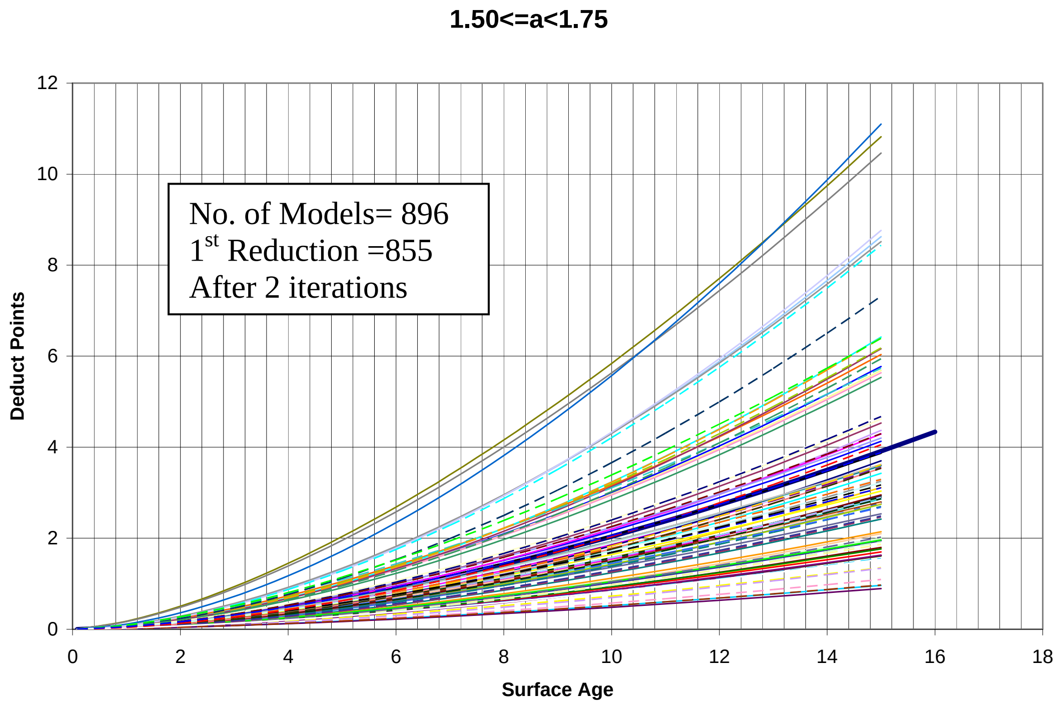


Figure 52

Initial model consolidation for TI model of ASP-RHS

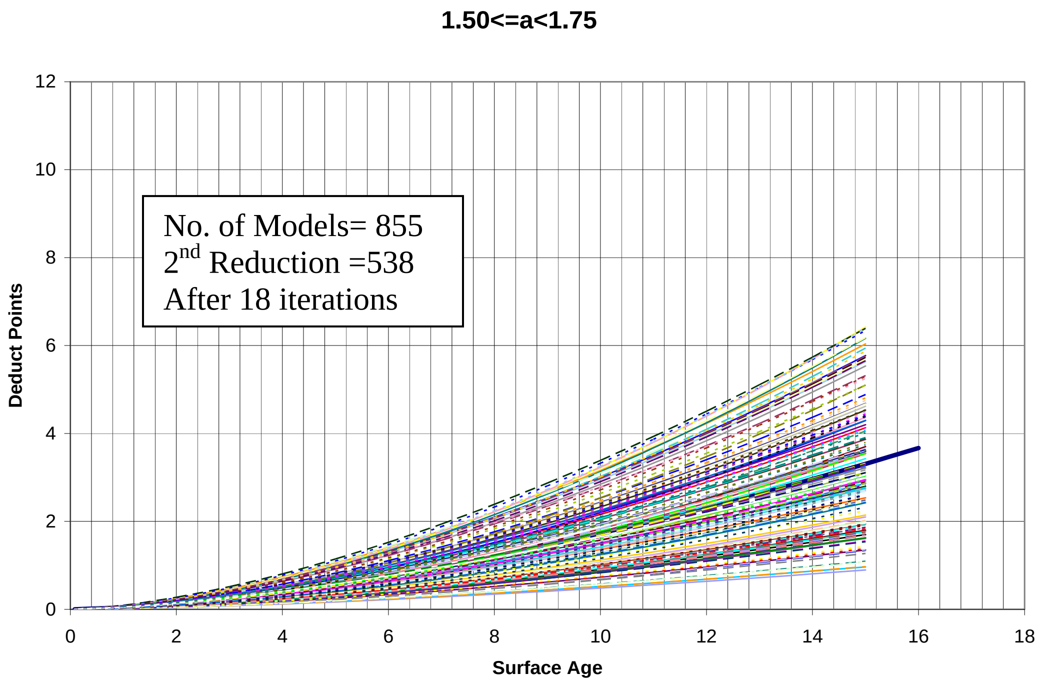


Figure 53

Final model consolidation for TI model of ASP-RHS

Table 8

Summary of control sections for middle consolidated model of roughness index for flexible pavements-IHS (a = 0.75 to 1.0)

$$RI = 100 - 2.199 \cdot SA^{0.813}$$

450-11	450-13	450-36	450-43	454-04

Table 9

Summary of control sections for lower consolidated model of rutting index for flexible pavements-NHS (a = 0.75 to 1.0)

$$RTI = 100 - 2.82 \cdot SA^{0.878}$$

006-03	012-13	019-02	023-04	025-03	050-06	195-03
008-02	014-06	022-06	024-01	025-04	058-02	417-02
010-06	015-04	023-03	025-02	034-05	074-03	835-17

Table 10

Summary of control sections for upper consolidated model of transverse cracking index for flexible pavements-RHS (a = 1.50 to 1.75)

$$TI = 100 - 0.044 \cdot SA^{1.60}$$

003-07	126-03	195-30	237-02	291-01	368-03	839-13	849-34	859-03
005-05	127-04	197-04	256-07	301-03	372-01	840-19	849-38	859-07
010-06	128-03	198-01	256-08	303-02	373-01	840-33	849-45	859-24
033-01	131-04	203-02	256-09	304-01	375-02	844-02	852-12	859-25
033-02	134-02	209-01	256-10	305-01	382-04	845-06	852-16	861-18
038-02	134-04	209-02	257-02	307-01	386-01	845-17	852-26	861-19
040-04	138-04	210-04	260-10	319-05	397-03	845-19	853-02	862-17
052-05	143-04	211-01	260-11	324-02	398-01	846-02	853-03	863-06
052-08	149-04	211-30	264-03	328-02	399-01	846-10	853-09	863-07
053-05	153-01	213-02	264-04	340-01	407-01	846-12	853-12	863-09
056-30	161-09	220-03	266-01	346-02	412-02	847-05	853-39	864-03
065-06	168-01	222-04	270-03	348-02	830-17	848-05	854-13	-
090-04	168-02	224-02	273-03	349-02	832-05	848-17	857-04	-
094-02	175-02	228-07	278-05	350-03	832-13	849-08	857-63	-
097-01	179-01	230-01	279-01	352-01	832-23	849-10	857-68	-
100-02	182-01	230-03	279-04	357-01	835-19	849-13	858-01	-
109-03	184-01	235-01	284-02	357-02	839-08	849-16	858-05	-
110-01	195-01	236-01	286-01	365-01	839-11	849-20	858-11	-

Table 11

Summary of control sections used for verification of consolidated models for ASP-SHS

Control Section	a	10^b	R^2	Observa-tions	SSE	P-Value <0.05	Model	Consolidated Model
009-04	0.809	2.02	0.94	108	2.31	0k	Lower	$RI = 100- 2.369*(SA)^{0.879}$
036-04	0.772	5.14	0.91	261	9.90	0k		
192-01	0.914	1.73	0.98	115	1.32	0k		
204-03	0.856	2.51	0.96	160	3.57	0k		
207-02	0.936	2.52	0.98	226	2.49	0k		
216-01	0.987	1.22	0.99	132	1.08	0k		
230-03	0.920	1.99	0.96	99	3.03	0k		
274-30	0.908	2.69	0.93	34	1.39	0k		
313-01	0.933	2.15	0.99	96	0.52	0k		
389-03	0.877	1.71	0.92	86	3.93	0k		
009-04	0.771	1.57	0.96	108	1.41	0k	Middle	$RI = 100- 1.427*(SA)^{0.901}$
036-04	0.791	2.87	0.93	261	7.97	0k		
192-01	0.955	1.16	0.99	116	0.85	0k		
204-03	0.934	1.39	0.98	159	2.36	0k		
207-02	0.899	1.95	0.99	225	1.48	0k		
216-01	0.918	1.00	0.99	134	0.66	0k		
230-03	0.943	1.17	0.99	97	0.96	0k		
274-30	0.964	1.37	0.97	31	0.66	0k		
313-01	0.986	1.36	0.99	101	0.60	0k		
389-03	0.888	0.99	0.97	85	1.08	0k		
009-04	0.821	0.99	0.94	114	2.92	0k	Upper	$RI = 100- 1.038*(SA)^{0..898}$
036-04	0.865	1.48	0.81	271	29.27	0k		
192-01	0.892	0.97	0.98	121	1.20	0k		
204-03	0.939	0.99	0.94	171	6.69	0k		
207-02	0.927	1.29	0.97	232	3.76	0k		
216-01	0.860	0.87	0.99	138	1.12	0k		
230-03	0.892	1.00	0.99	110	0.94	0k		
274-30	0.925	1.09	0.96	40	1.07	0k		
313-01	0.939	1.07	0.98	102	1.00	0k		
389-03	0.830	0.85	0.96	92	1.53	0k		

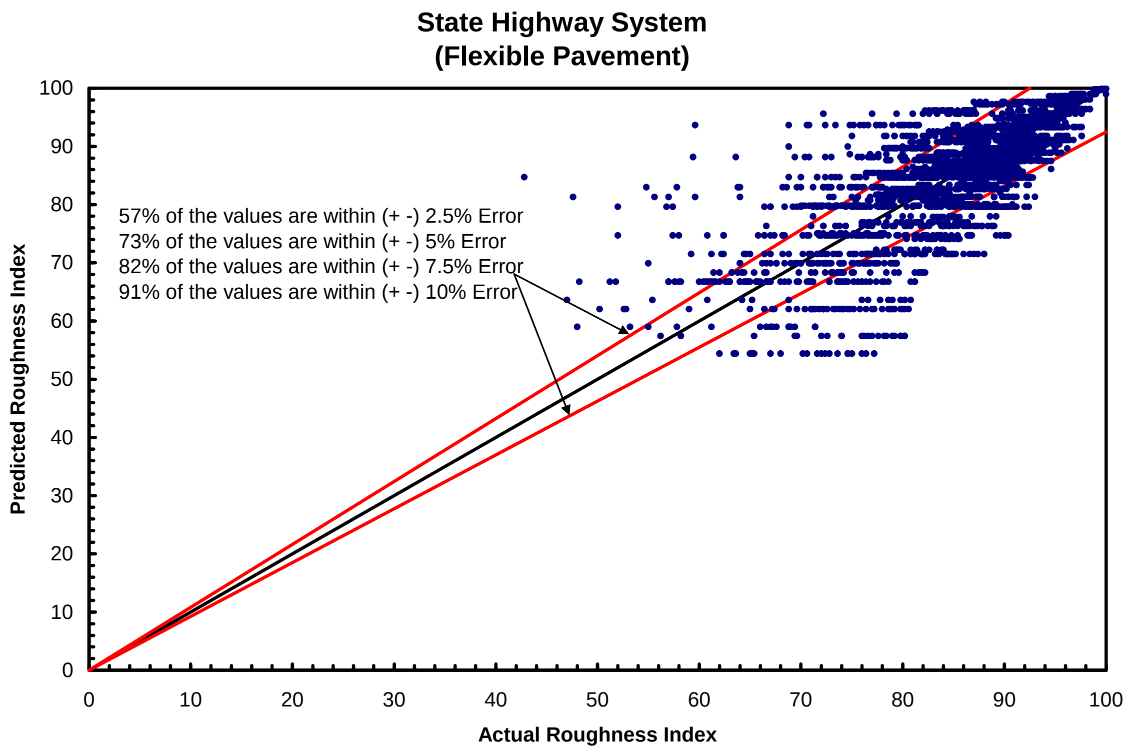


Figure 54
Predicted versus actual RI values using the consolidated models for RI of ASP-SHS

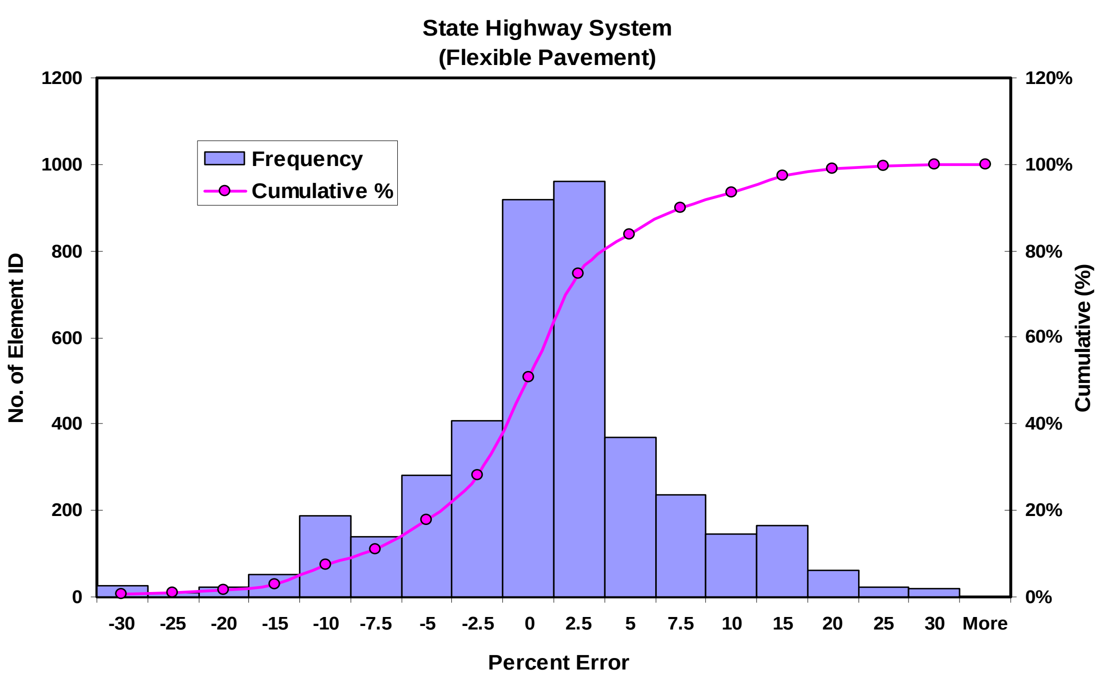


Figure 55
Distribution of percent error for predicted versus actual RI using the consolidated models for RI of ASP-SHS

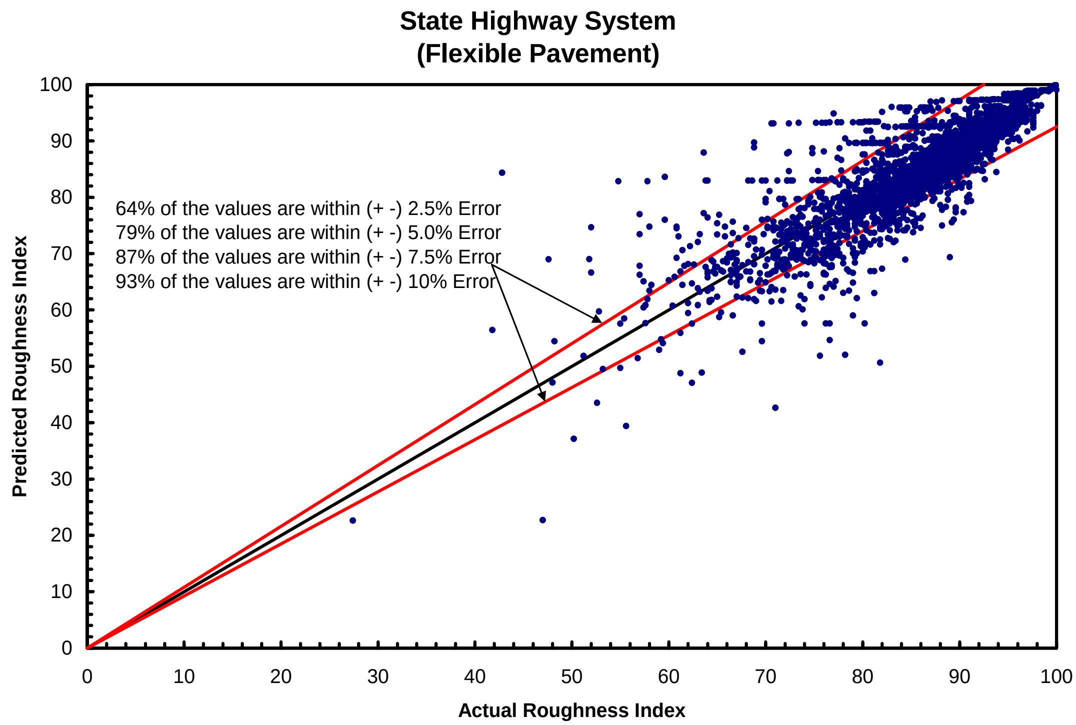


Figure 56
Predicted versus actual RI using the consolidated models and the current index value for ASP-SHS

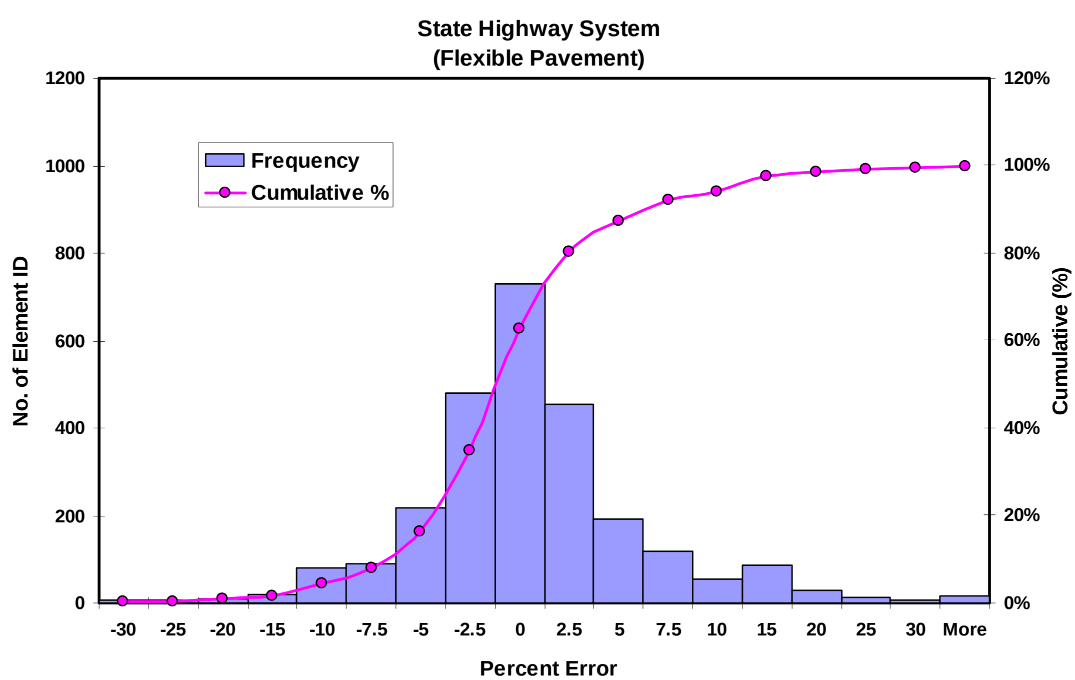


Figure 57
Distribution of percent error for predicted versus actual RI using the consolidated models and the current index value for ASP-SHS

Generalized Pavement Performance Models

Generalized models are commonly known as family curves that are developed for each distress type, pavement type, and highway classification and are a function of "age." Various such models were developed in this study and the summary of the results are reported in Appendix D. The generalized model developed for RI of ASP NHS [equation (23)] was used to predict RI values of randomly selected control sections. The selected control sections are the same for LADOTD family curve predictions (Figure 23). Figure 58 shows the predicted versus the actual RI index values. The figure depicts a good agreement between the predicted and the actual RI values, indicating that the model was able to predict the condition of the road reasonably well. Percentage errors between the actual and predicted values were also calculated, and a histogram was generated as shown in Figure 59. It is evident from the histogram that the error is randomly distributed. Moreover, approximately 52, 65, 74, and 80 percent of data values are within (±) 2.5, 5, 7.5, and 10 percent error, respectively.

The comparison of the two error distributions (family curves and generalized models) and the predicted versus actual values shown in Figures 23, 24, 58, and 59 clearly indicates that the generalized models provide better predictions of RI values.

Similar results were obtained for the longitudinal index of ASP NHS and roughness index of IHS COM as illustrated in Figure 60 and 61, respectively. Comparison of Figures 24, 25, 60, and 61 depicts that generalized models exhibited better predictions relative to the existing LADOTD family curves. For example, the data in Table 12 indicate that the LADOTD family curve predicts 58 percent of data within 5 percent error; however, the new model shows 79 percent of data within 5 percent error. This reflects an improvement of 21 percent.

Table 12
Summary of the comparison between the LADOTD family curve and generalized models for longitudinal cracking index of NHS ASP

Percent Error	Percent of Data Set		Percent Improvement
	LADOTD Family Curve	Generalized Model	
2.5	44	71	27
5.0	58	79	21
7.5	79	94	15
10	89	96	7
15	98	99	1

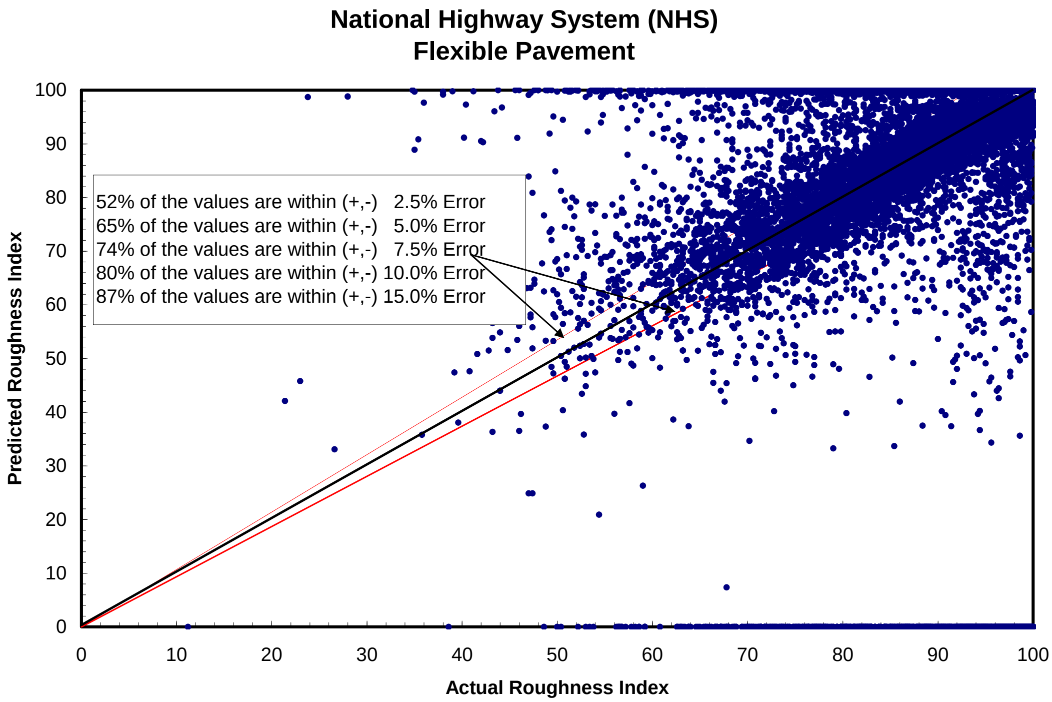


Figure 58
Predicted versus actual RI values based on generalized model-NHS

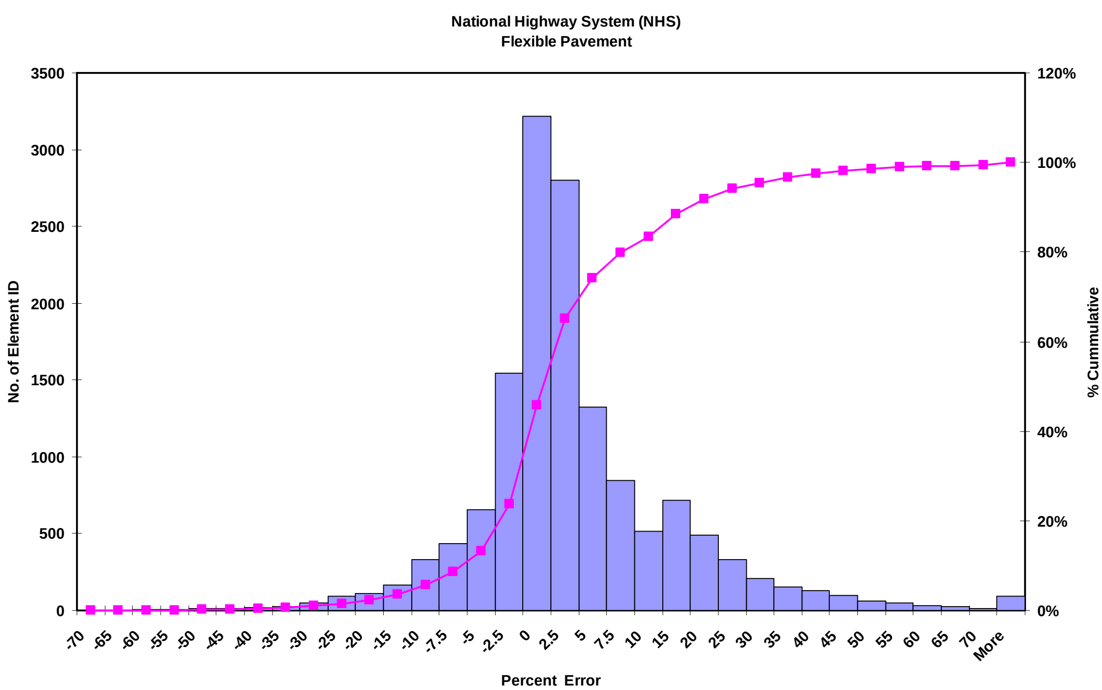


Figure 59
Percent error between actual and predicted values for a generalized model NHS

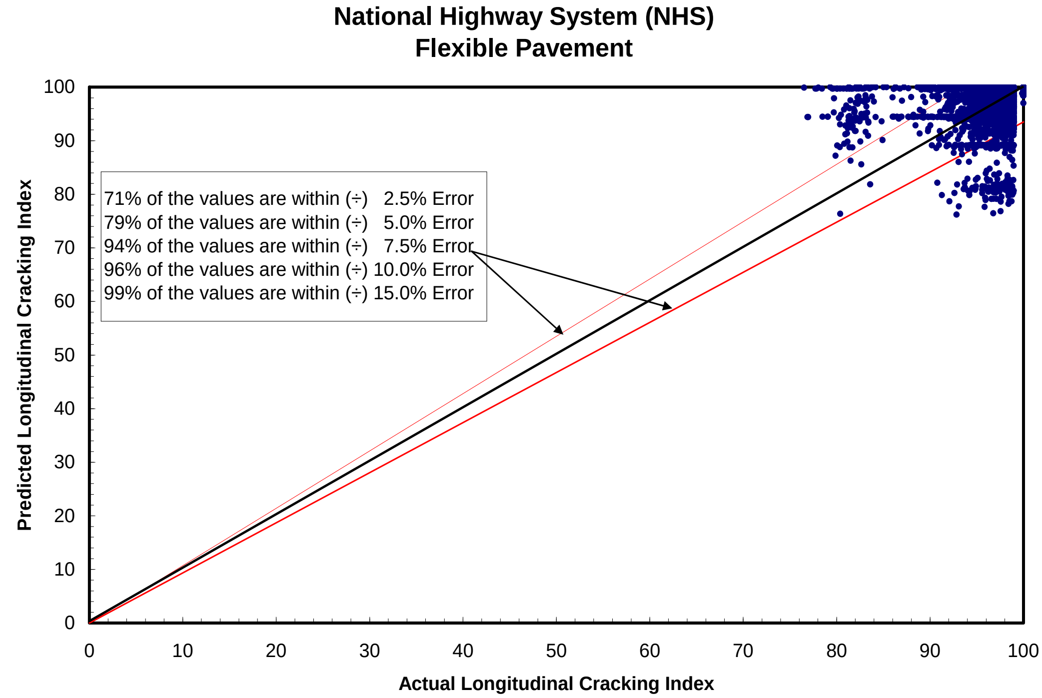


Figure 60
Predicted versus actual LI values based on generalized model NHS-ASP

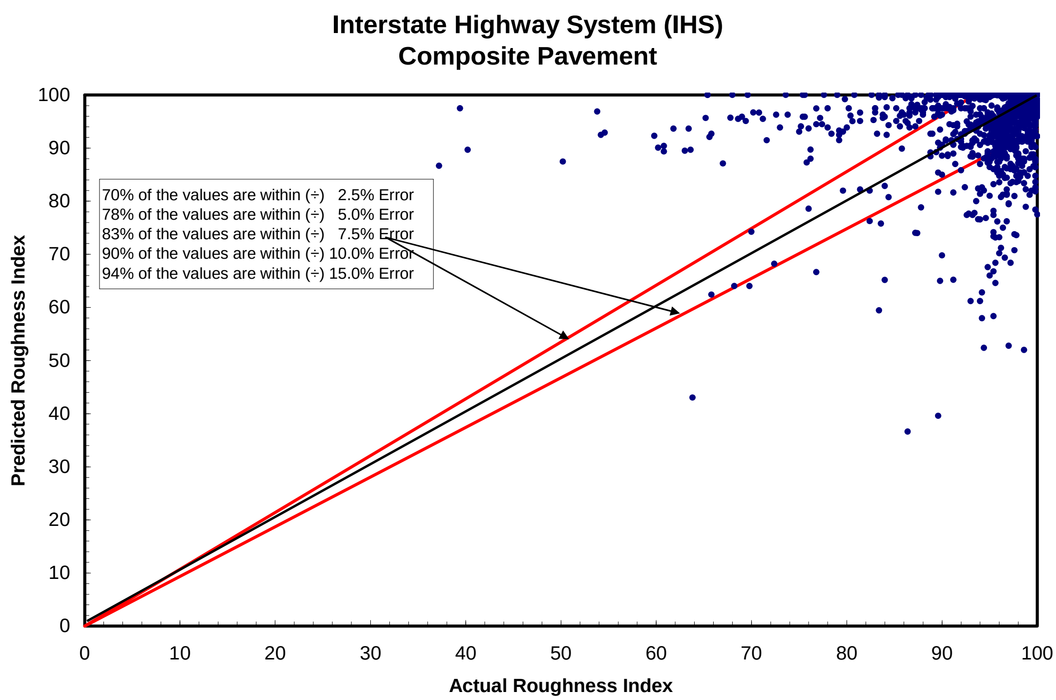


Figure 61
Predicted versus actual RI values based on generalized model HIS-COM

Network Condition Assessment

The pavement performance models can be utilized to assess the overall pavement network condition based on a certain distress type. Figures 61 and 62 show the distribution of the RI of NHS for the randomly selected control sections for the year 2005 and 2010. In Figure 61, the year 2005 data are the actual RI values, and the year 2010 data represent the predicted values using the LADOTD family curve. It can be seen from the figure that based on the LADOTD maintenance threshold RI index of 85, about 35 percent of the pavement sections required maintenance in the year 2005. The LADOTD family curve predicted that approximately 91 percent of the section will need some type of maintenance action in the year 2010. On the other hand, 5 percent of the pavement sections that needed major rehabilitation in year 2005 increased to 36 percent in 2010, as predicted by the family curve.

The predicted RI distribution of the same pavement sections for the year 2010 using the new individual control section models is also shown in Figure 63. The data in the figure reveal that 65 and 18 percent of the pavement sections are in need of maintenance and major rehabilitation actions, respectively. Since the individual models represent the actual data trend, the aforementioned observations indicate that the existing LADOTD RI family curves underestimates the condition of the highway.

Figures 64 and 65 were generated to compare the network conditions as predicted by the existing LADOTD models, the newly developed generalized models, and individual control section models. It is obvious that newly developed models are in agreement with each other in assessing the network condition. The newly developed models are more reliable than existing models because the models represent the actual data trend based on the last 10 years. Although the generalized models and individual control section models are exhibiting similar results, one should note that the individual control section models are more precise than the generalized models. Nevertheless, the existing LADOTD models underestimate the network condition.

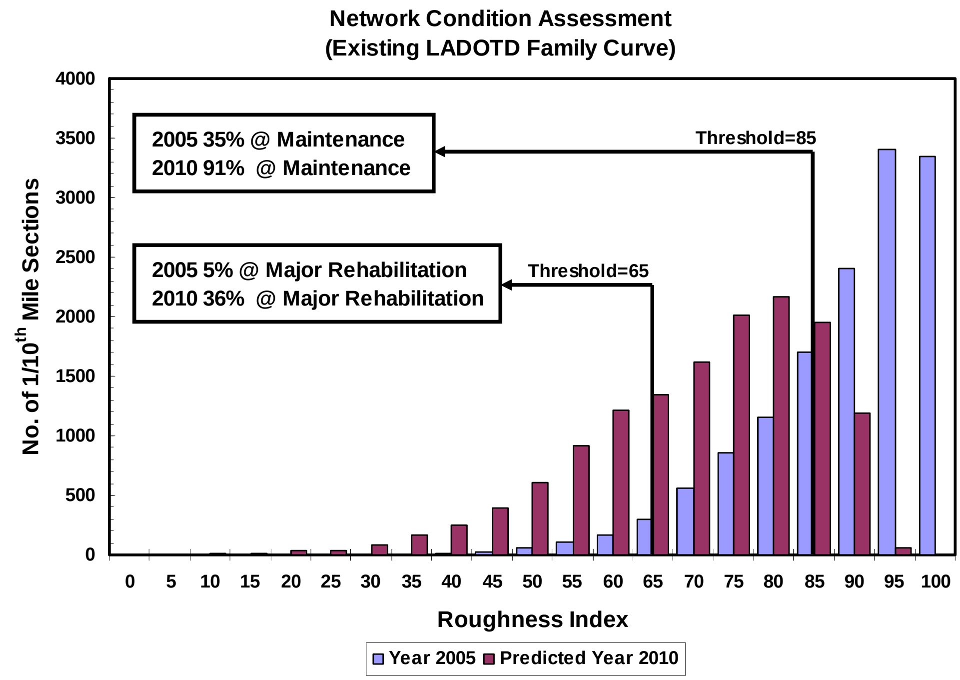


Figure 62
Network condition assessment for randomly selected NHS control sections using RI and LADOTD family curve

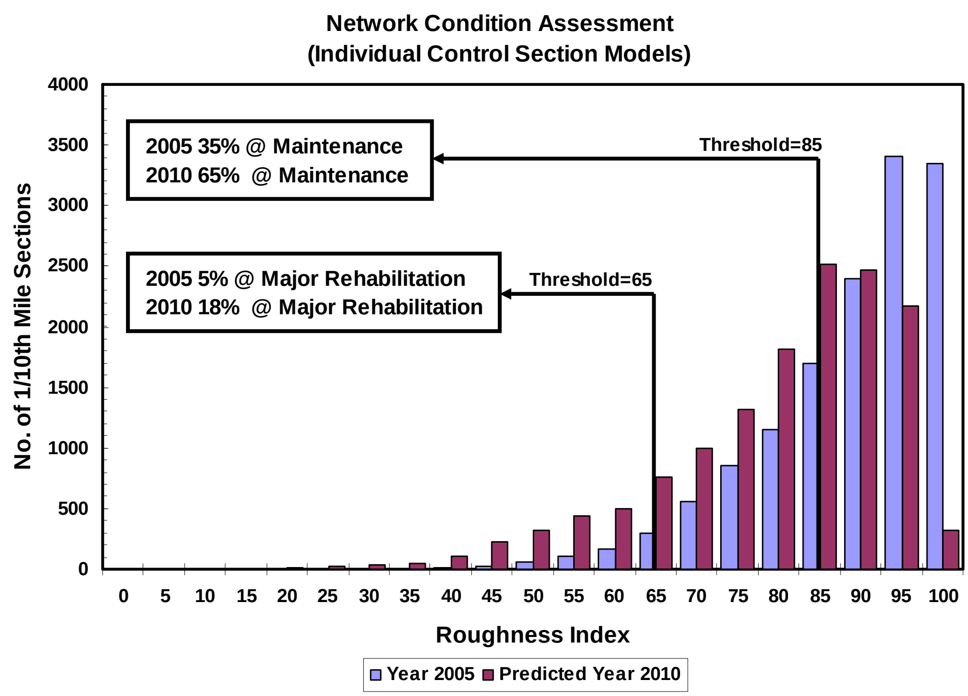


Figure 63
Network condition assessment for randomly selected NHS control sections using RI and individual control section models

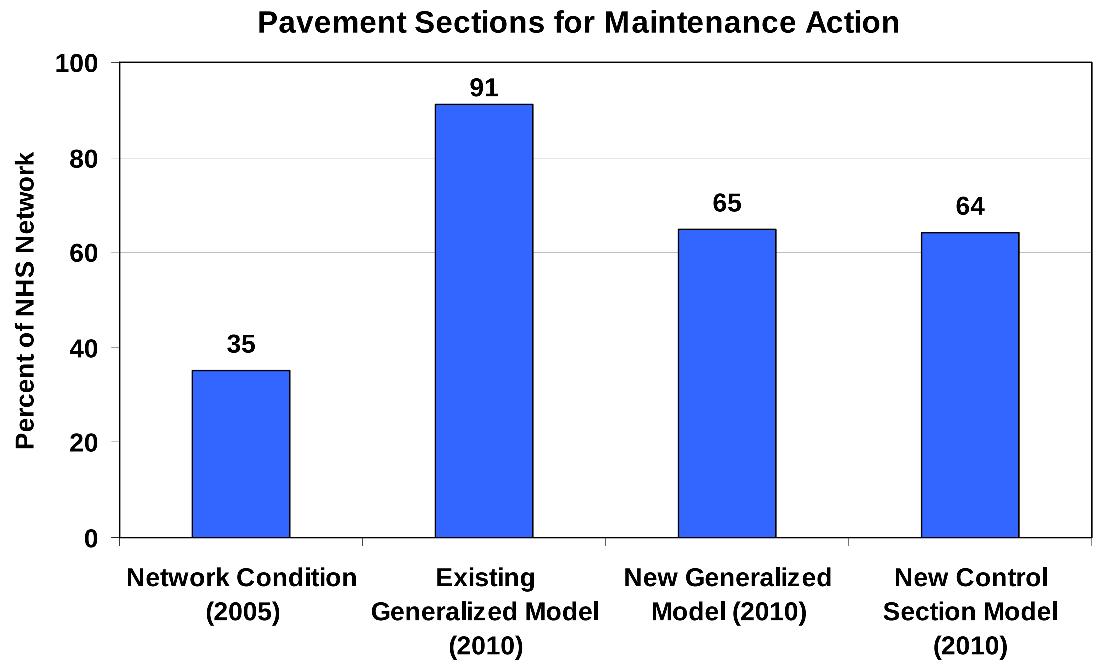


Figure 64
Comparison of Network condition for randomly selected NHS control sections using existing LADOTD and newly developed models (maintenance action)

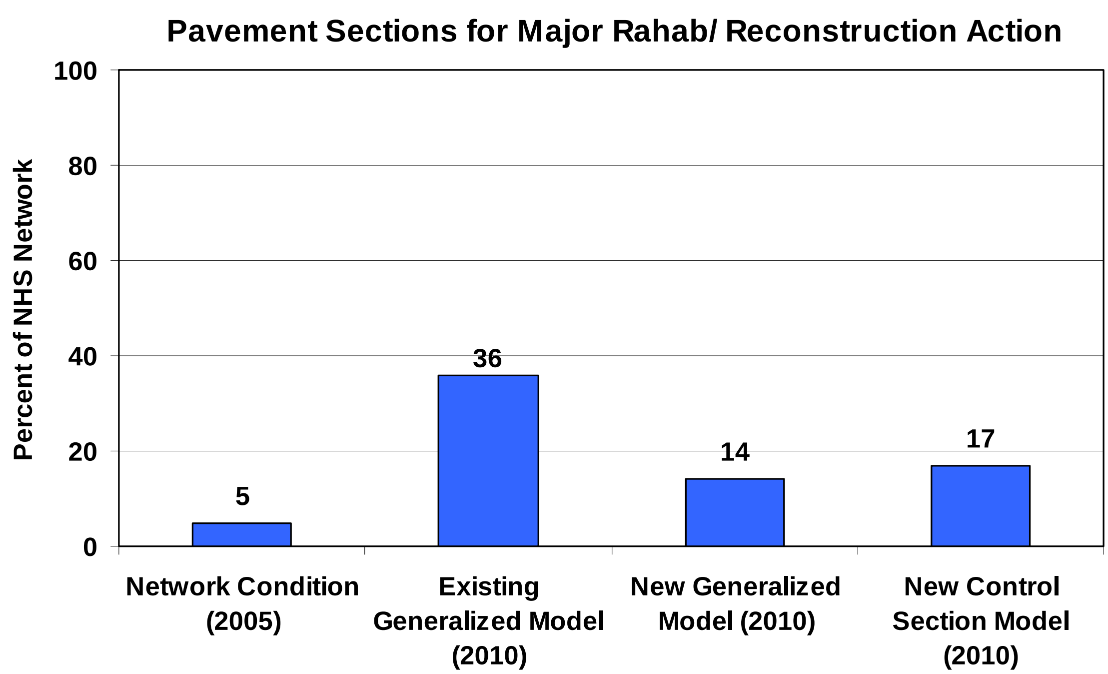


Figure 65
Comparison of network condition for randomly selected NHS control sections using existing LADOTD and newly developed models (rehab/reconstruction action)

Treatment Performance Evaluation

Treatment Performance Models and Treatment Life

In order to investigate the effect of treatment, the index distribution of the year prior to the treatment was generated as shown in Figures 66 and 67 for microsurfacing and a 2-in overlay, respectively. Each element ID was clustered into subgroups based on the index distribution and modeled uniquely by generating a regression model for the data set as shown in Figures 68 and 69. The data in the figures illustrate that there is some overlap between the data points that were clustered based on prior condition of the pavement. It can also be observed from Figure 68 that for the same threshold value of 85, the pavement sections with higher index values (85-90) prior to the microsurfacing treatment exhibited a surface life of 10 years, and the ones with lower prior index values (< 80) showed a surface life of 8 years.

In addition to the aforementioned analysis, the treatment life was also determined. Recall the treatment life is defined as the surface age at which the condition of the pavement becomes the same as it was prior to the application of the treatment. For the control sections shown in Figures 68 and 69, the average index values prior to the micro-surfacing and the 2-in overlay were 83 and 76, respectively. It can be seen from the figures that it will take approximately 9.5 and 15 years for the pavement sections to reach the same average index values prior to the treatment. Therefore, the life of the micro-surfacing and 2-in overlay treatments for the given control sections are 9.5 and 15 years, respectively.

It should be noted that the life of the treatment is a function various factor including but not limited to the following:

- Prior condition of the pavement
- Age of the pavement
- Causes of the distress
- Methods of treatment application
- Surface preparation of pavement before treatment
- Type and classification of pavement, traffic, etc.

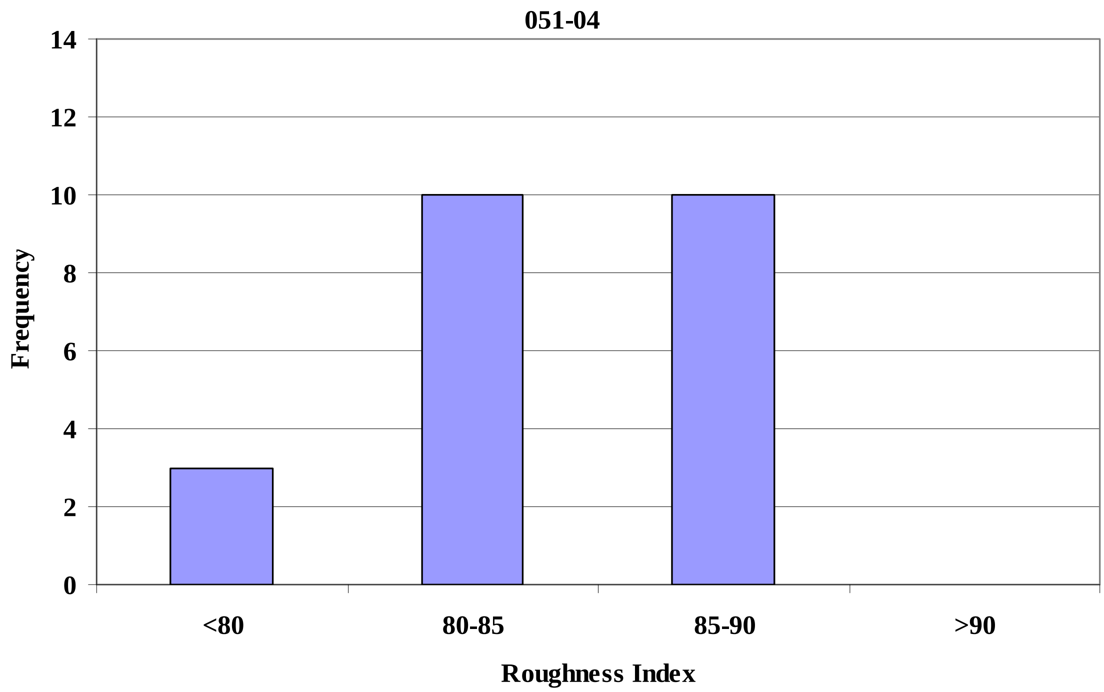


Figure 66

The index distribution of the year prior to the micro-surfacing treatment

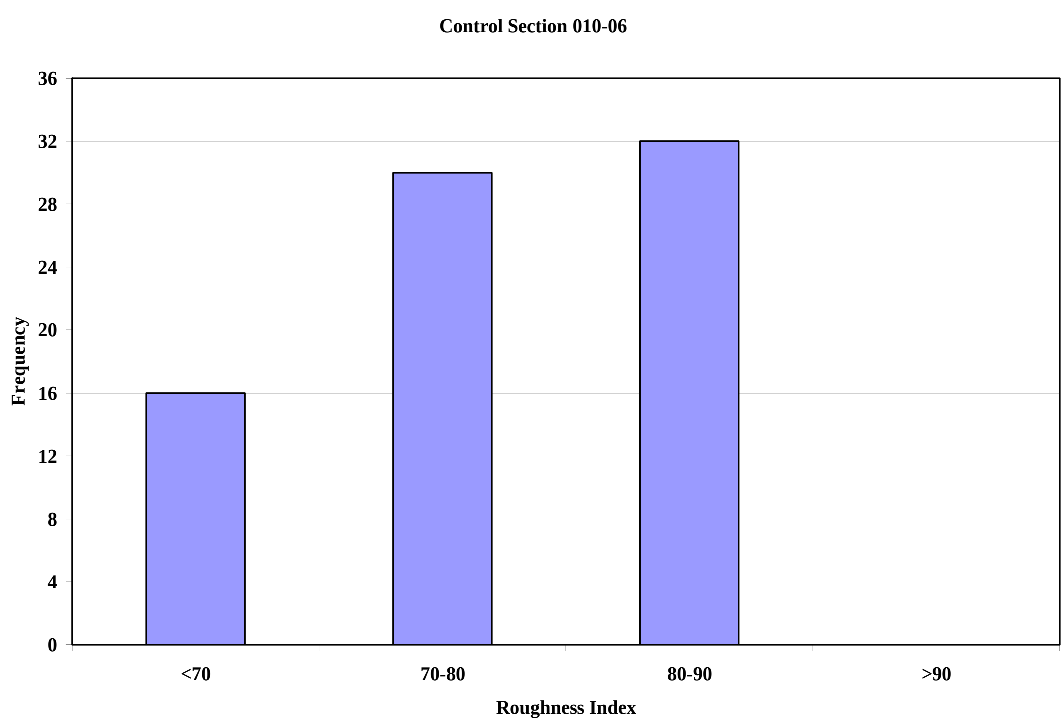


Figure 67

The index distribution of the year prior to the 2-in. overlay treatment

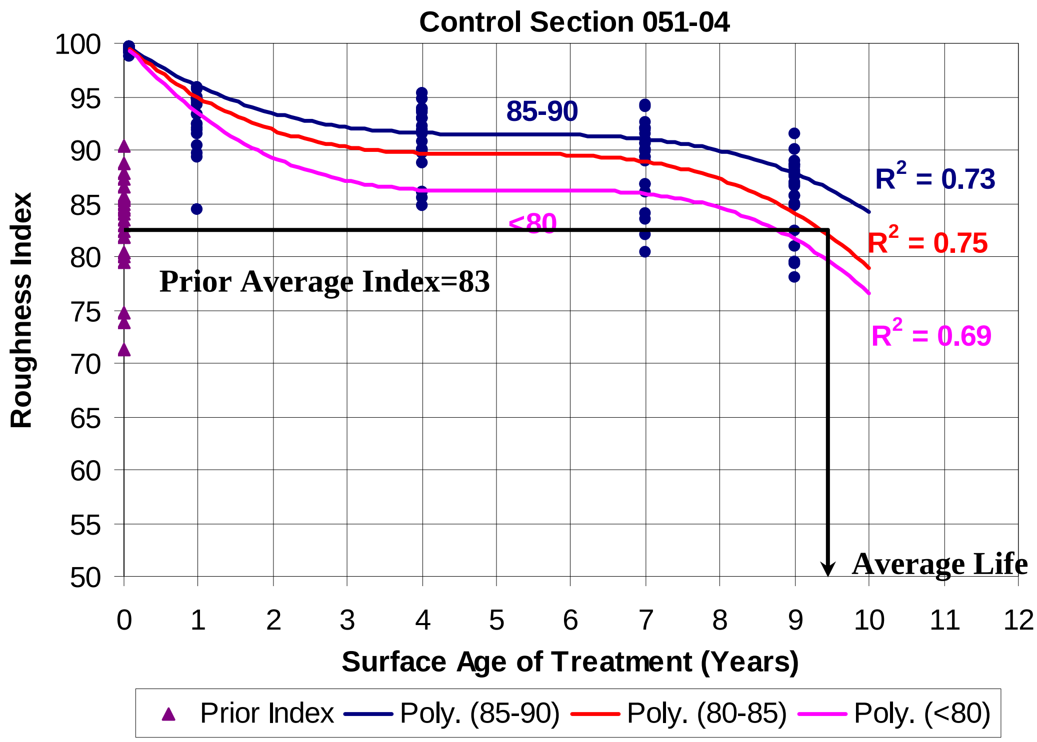


Figure 68
Performance model for micro-surfacing treatment on a composite pavement

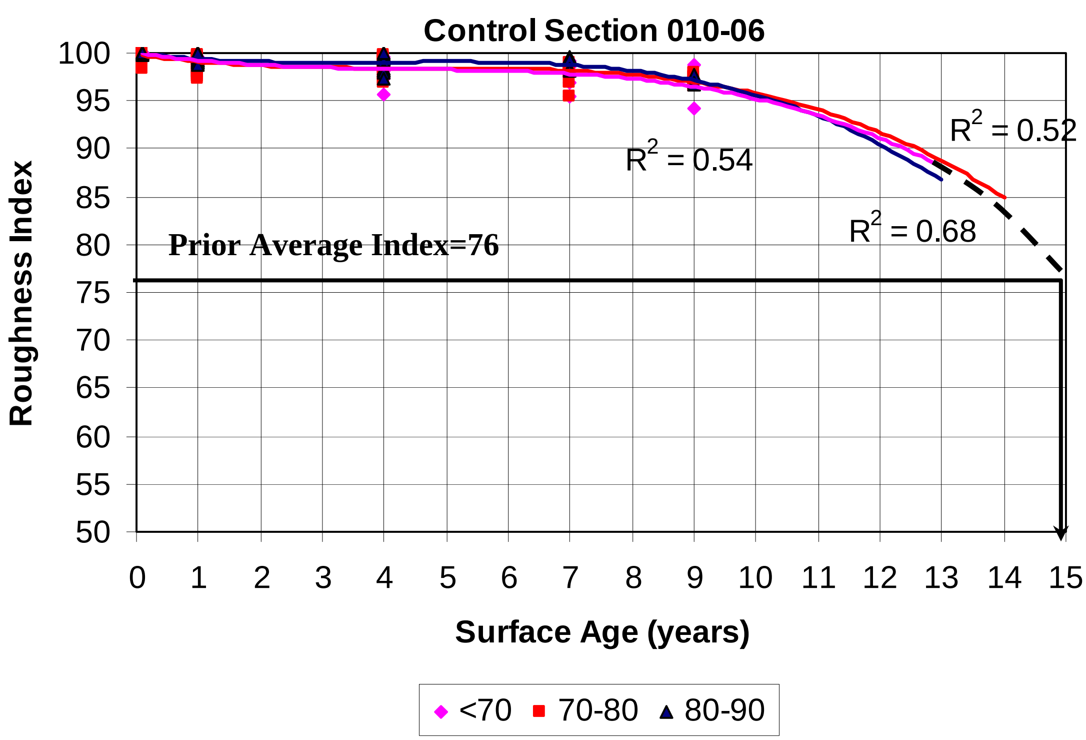


Figure 69
Performance model for 2-in. overlay treatment on a flexible pavement

In order to access the effect of prior condition of the pavement on the pavement treatment, the average index values for each subgroup (as shown in Figures 17, 66, and 67) prior to treatment were plotted as a function of the surface age of the subgroup for a threshold/trigger value of 85 (see Figure 70). The surface ages were predicted by the treatment models developed for each subgroup.

Note that the threshold/trigger value of the roughness index of 85 was selected to determine the surface age of treatment for each subgroup (which is the common trigger value for most LADOTD preventive/minor rehabilitation actions). Figure 70 clearly indicates that the surface age of the treatment actions is higher for pavement sections with high prior index values. This implies that pavement sections with higher index values prior to the treatment application performed better than those with lower index values. Stated differently, the treatment will be more effective if it were applied on pavement sections during the early stages of the pavement deterioration (low severity of distresses), thus achieving maximum benefits.

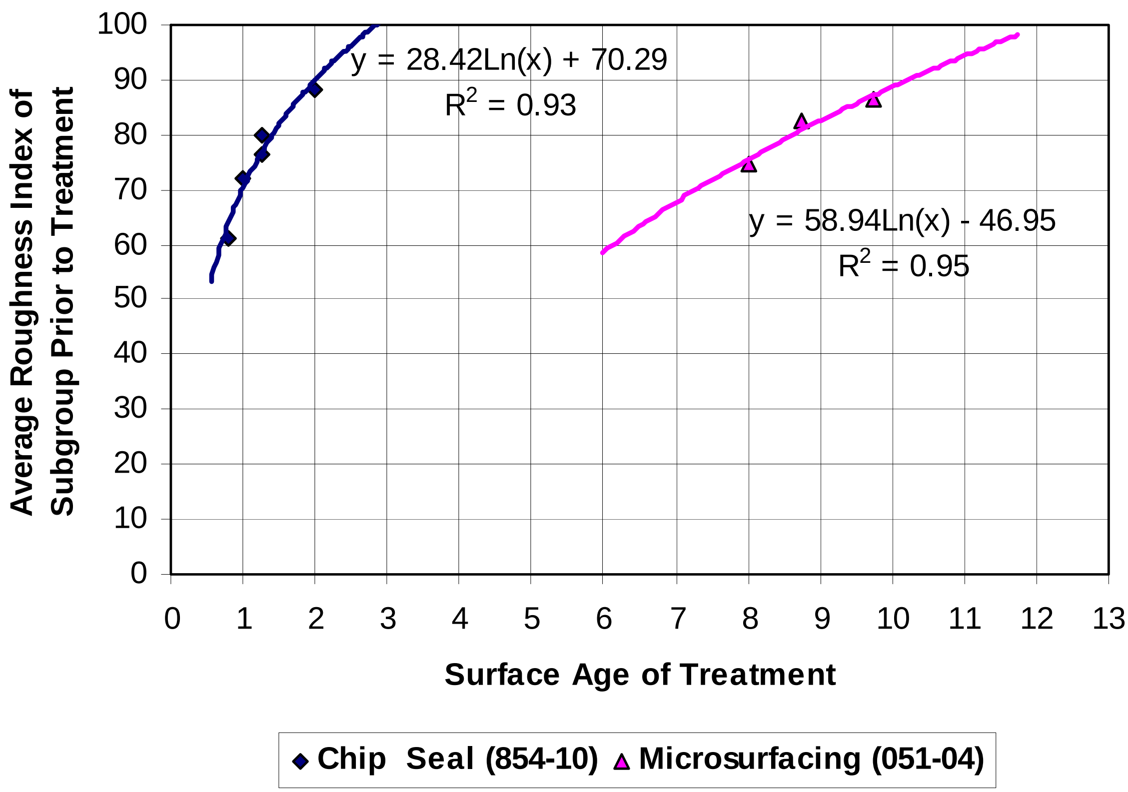


Figure 70

Average index values for each subgroup prior to the treatment as a function of the surface age for RI threshold/trigger value = 85

Treatment performance analyses were conducted for all selected projects for various types and classification of the pavements. The summary of the results are shown in Table 13. It can be seen from data in Table 13 that the overall average life for chipseal, microsurfacing, and 2-in overlay treatments for the selected projects are 6.4, 7.6, and 13, respectively. It should be noted that chip seal is further classified as a single, double, and triple surface treatment that can also affect pavement performance. Due to limited selected pavement sections and a lack of historical information, no such analyses were conducted in this study.

Table 13
Summary of average age of treatments for various pavement and highway system classifications

Treat-ment Type	Control Section	Begin Log-mile	End Log-mile	Pave-ment Type	Const-ruction Date	Major Rehab Date	High-way System	Average Index Before Treat-ment	Stan-dard Devia t-ion	Treat-ment Average Life	Pave-ment Age	Last Rehab Age
Chip seal	854-10	0.68	3.98	COM	1954	1979	RHS	74.3	9.3	3.5	43	18
	854-06	0	7.9	COM	1960	1960	RHS	73.5	9.5	6.0	37	37
	353-03	0	2.3	COM	1951	1978	SHS	61.0	5.0	4.0	46	19
	181-02	1.93	5.93	COM	1956	1965	NHS	65.5	15.2	8.5	41	32
	821-09	0.7	2.5	ASP	1952	1962	RHS	79.5	4.0	8.0	45	35
	821-11	0	5.1	ASP	1962	1962	RHS	63.0	16.0	7.0	35	35
	813-01	0	4.85	ASP	1963	1973	RHS	71.4	11.4	7.5	34	24
	165-03	0	6.02	ASP	1953	1973	NHS	73.1	10.3	3.5	44	24
2-inch Overlay	832-04	0	4	ASP	1970	1999	RHS	63.5	11.9	10.0	27	2
	010-06	0.3	8.2	ASP	1972	1982	SHS	76.7	8.2	13.5	25	15
	090-01	0	8.1	ASP	1953	1978	SHS	78.0	10.6	14.5	44	19
	013-07	0	10.9	COM	1957	1980	SHS	67.2	10.1	11.0	40	17
Micro-surfacing	261-03	0	5.12	COM	1947	1974	SHS	82.6	8.8	6.5	50	23
	051-04	0	2.39	COM	1940	1981	SHS	83.2	4.4	9.5	57	16
	026-03	3.42	6.01	COM	1962	1982	NHS	88.8	8.2	12	35	15
	148-01	0	1.45	COM	1948	1971	NHS	86	5	8.5	49	26
	410-01	1.69	2.8	COM	1958	1969	NHS	74.5	5	2	39	28
	451-07	11.01	17.49	COM	1981	1988	IHS	94	3.3	7	16	9

In order to evaluate the effect of the pavement's prior condition on pavement performance, average index values prior to the treatment for the selected projects were also plotted as a function of the average life of the treatments as shown in Figure 71. It is evident from the figure that for micro-surfacing and 2-in overlay treatment, the average treatment life increases as index values prior to treatment increase. For micro-surfacing, the treatment life will be about

4 years if it were applied at prior index value of 80. This life will increase to 12 years if the treatment application were done at the index value of 90. Stated differently, for every five-unit change in prior index value, the increase in treatment life is 4 years. Similarly for 2-in. overlays, the five-unit change in index value causes an increase of 1.6 years in treatment life.

In case of chip seal treatment, prior index values did not exhibit any relationship with the average life of the treatment. It may be due to the fact that the chip seal treatment could be applied as a single, double, and triple surface treatment that can aid in varying performance of the treatment. Furthermore, the type and classification of the pavement can affect the treatment performance. Therefore, evaluating the treatment performance on the pavement type and highway classification can further help in understanding the given trend.

Figure 71 can also be used to establish treatment threshold index values. For example, for 7 and 12 years of expected life of micro-surfacing and 2-in. overlay, the threshold hold index value based on roughness index would be approximately 85 and 70, respectively.

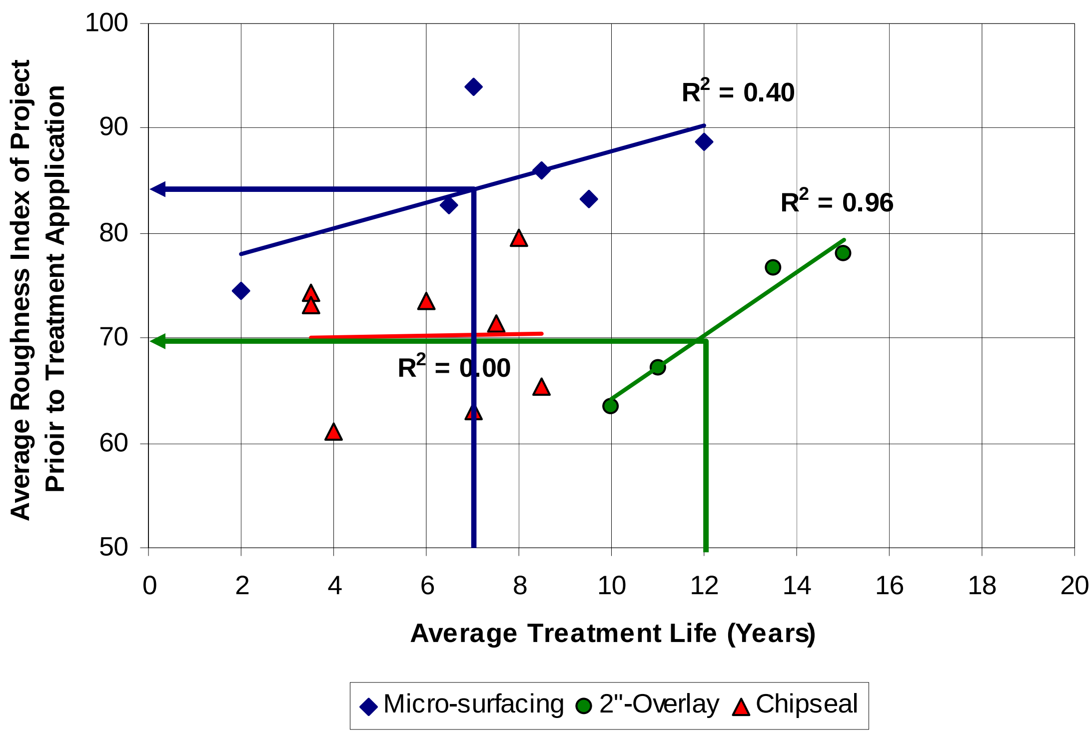


Figure 71
Average RI values prior to the treatment as a function of the average life of the treatment

Review of LADOTD Pavement Treatment Selection Models

The materials in this section are based on the review of the LADOTD's practice regarding the selection of the appropriate treatments of the various pavement types and classes.

LADOTD's practice is mainly based on several types of analyses of pavement distress as presented below.

- Pavement performance curves (see Table 6 for the various pavement performance formulas used by the LADOTD).
- Distress index deduct points, which are based on the type, severity level, and extent of the distress (see Appendix E).
- Distress index formulas (see Appendix E)
- Treatment trigger levels (see Appendix E).

Finally, LADOTD also uses the pavement rating scheme provided in Table 14 for the purpose of communication with the traveling public and the legislatures.

Table 14
Pavement rating based on the performance index

Rating	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

Examination of the types of treatments listed in Appendix E indicates:

1. The types of treatments listed are very popular and are being used by many state highway agencies. However, the number of treatments can be expanded to include other pavement preservation options. For example, flexible pavements treatments can be expanded to include re-construction, pulverizing and resurfacing thin or medium overlays without milling, white topping, and so forth.

2. The treatment selection is based mainly on the values of the distress index of several distress types, which indicates the pavement rating (very good, good, fair, poor, or very poor). The value of the index does not express the pavement rate of deterioration. For example, two jointed concrete pavement sections having exactly the same composite

distress index value of 85 in 2002 may or may not have the same composite distress index in 2004. The trigger values could be substantially improved if they are based on the RSL (remaining service life) of the pavement section in question. The RSL expresses both the pavement conditions (index value) and the pavement rate of deterioration.

3. The preferred treatments are independent of the causes of the pavement distresses. The ideal scenario is that the preferred treatment is selected based on the distress types and the causes of the distress (not included in the treatment tables). As an alternative, a second set of tables or matrices where the preferred treatment option is selected on the basis of the causes of distress can be developed as a second tear of decision making. That is, the treatment option is selected from tables in Appendix E and then verified based on the causes of distress. However, this represents a long-term improvement of the treatment selection practice. For an illustrative purpose for flexible pavements, the possible causes of five distress types (alligator cracks, block cracks, longitudinal cracks, transverse cracks, and rut) are listed in Tables 15 and 16. The two tables can be tailored to the causes of distress in the state of Louisiana using proper forensic investigations and data analyses. The main reason for the selection of the preferred pavement treatment based on the types and causes of the distresses is that such a selection would result in the most cost effective treatment. To illustrate, consider two flexible pavement sections having longitudinal cracks. The cracks in the first section are located in the vicinity of the wheel paths and are top-down cracks; whereas, the cracks in the other section are bottom-up cracks. When such information is available, the treatment for section 1 should be carried out very early (very high distress index), and it should consist of milling and filling 1-inch or less of pavement. The treatment for section 2, on the other hand, could be full-depth patching.

4. The pavement treatments listed in Appendix E are based on a different denominator. The treatments for jointed concrete pavements are a function of transverse and longitudinal cracks. For flexible pavements, all cracks are lumped together and labeled "random cracks." The cost-effective treatments for flexible pavements having transverse cracks are not the same as those for flexible pavements having edge or longitudinal cracks. Hence, separating the random cracks category into its constituents would improve the treatment selection process.

5. Although the most cost-effective treatment could have been selected, the construction process could have an adverse effect on the performance of the treatment. Hence, example recommendations of what should be done and what should not be done during construction should be developed and made available to pavement contractors and various regions. Examples of such recommendations are listed in Tables 17 and 18.

Table 15

Possible causes of five flexible pavement distresses

Distress Type	Possible causes
Alligator Cracking	1. Insufficient base support or low base shear strength. 2. Insufficient compaction. 3. High air voids. 4. Low tensile strength of the AC. 5. Poor drainage. 6. Inadequate structural strength of the aggregate base (the cracks resemble shear cracks, the longitudinal cracks may or may not be connected by transverse cracks and the affected area remains confined to the wheel paths until shear failure takes place). 7. Inadequate AC thickness or inadequate structural capacity. 8. Incompatible stiffness of the pavement layers.
Block Cracking	1. Low tensile strength of the AC mixture. 2. Hardening of the asphalt binder over time and/or excessive aging of the asphalt binder during the mixing process.
Longitudinal cracks	1. Insufficient base support or low base shear strength (for edge and wheel paths). 2. Poor construction (for centerline and center of lane). 3. Low tensile strength of AC (if transverse crack is present). 4. Material loss due to water sensitivity between the aggregate and binder (stripping, for center of lane). 5. Mix segregation. 6. Poor drainage. 7. Inadequate structural strength (for edge and wheel paths).
Rut	1. High asphalt content. 2. Insufficient base support or low base shear strength. 3. Insufficient compaction. 4. Poor construction. 5. Excessive amount of filler and/or sand. 6. Excessive non-angular aggregates. 7. High or low air voids. 8. Material loss due to water sensitivity between the aggregate and binder (striping). 9. Mix segregation. 10. Poor drainage. 11. Inadequate structural strength. 12. Wrong grade of asphalt.
Transverse Cracks	1. Low tensile strength of AC mixture. 2. Poor drainage. 3. Temperature sensitive asphalt. 4. Wrong grade of asphalt. 5. Hardening of the asphalt binder.

Table 16

Commonality between the possible causes of five flexible pavement distresses

Possible causes of distress	**Distress Type**				
	Alligator Cracking	**Block Cracking**	**Longitudinal Cracking**	**Transverse Cracking**	**Rut**
Insufficient base support or low base shear strength.	X		X		X
Insufficient compaction	X				X
High air voids	X				
Low tensile strength of the AC	X	X	X	X	
Poor drainage	X		X	X	X
Inadequate structural strength of the aggregate base (the cracks resemble shear cracks, the longitudinal cracks may or may not be connected by transverse cracks and the affected area remains confined to the wheel paths until shear failure takes place).	X		X		X
Incompatible stiffness of the pavement layers	X				
Inadequate AC thickness or inadequate structural capacity.	X				
Hardening of the asphalt binder over time and/or excessive aging of the asphalt binder during the mixing process.		X		X	
Poor construction			X		X
Mix segregation			X		X
Stripping			X		X
High asphalt content					X
High or low air voids					X
Excessive amount of passing sieve number 200 (>7%)					X
Asphalt grade				X	X

Table 17
Example-recommendations for full and partial depth bituminous patch of flexible pavements

Treatment	Recommended Actions	Actions Not Recommended
Micro-surfacing	• Seal all existing cracks. • Patch all areas suffering from medium and high severity distress. • Check bridge clearance. • Restore the ride quality in areas suffering from high severity surface roughness. • Fill and level all rut channels. • Remove all areas experiencing shoving and/or corrugation by milling and filling.	• Do not use microsurfacing to enhance the structural capacity of the pavement. • Do not microsurface distressed areas. • Do not microsurface block or alligator (fatigue) cracked pavements.
Seal pavement	• Remove loose material from cracks.	• Do not apply excessive amount of seal or overfill the cracks.
Repair transverse and longitudinal distress, and patches (Type III repair)	• Repair affected areas only. • Saw all cuts. • Remove all loose pieces. • Feather all construction joints. • Check the quality and integrity of the drainage system.	• Do not overlap patches. • Do not patch an area less than 2-feet in width or length. • Do not damage the underlying asphalt course or aggregate base.

Table 18
Example-recommendations for chip seal and crack seal of flexible pavements

Treatment	Recommended Actions	Actions Not Recommended
Chip seal	• Remove loose material from the pavement surface. • Patch the existing pavement prior to chip seal if medium and/or high severity distress extends to the bottom of the asphalt concrete. • Seal or fill all transverse and longitudinal cracks. • Spray the emulsified asphalt evenly over the pavement surface. • Apply the chip evenly over the entire pavement surface. • Be sure that the chip seal operation is preserving or restoring the crown (transverse slope) to the pavement surface.	• Do not use on high volume roads. • Do not use to enhance the structural capacity of the pavement. • Do not use on wet pavement surfaces. • Do not use at stop signs or traffic light or in acceleration and deceleration areas. • Do not use on block or alligator cracked pavements or on raveled pavement surface.
Crack seal	• Remove loose material from cracks. • Use the proper crack-seal material. • Place the seal nozzle over the crack at one end of the crack and seal in one direction. • Keep the nozzle close to the center (mid width) of the crack. • Set the proper pressure in the seal line so that the proper amount of seal is supplied through the nozzle.	• Do not allow the seal material to cover a significant portion of the pavement around the crack. • Do not allow the seal line to drip extra seal material over the pavement.

Given the four pavement types in Louisiana, the pavement treatment program can be divided, in general, into 15 categories depending on the pavement and treatment types as shown in Table 19. The left hand column of the table lists the existing pavement type before the application of any treatment, rehabilitation, or re-construction. The other four columns in the table list the transformation of the pavement type from one category to another depending on the treatment type. Table 19 can provide a guideline to keep the continuity of PMS database. For example, before treatment a CRC (CR) pavement could be reconstructed as flexible (CRF), as jointed (CRJ) or it could be overlaid with asphalt concrete to become composite (CRC) pavement. Each cell in Table 19 consists of one or more treatments. For example, the cell labeled FF (an existing flexible pavement remains flexible after treatment) contains all the treatment options listed in Appendix E. The main advantage of using the symbols provided in Table 19 is the continuity of the data of the PMS database. For example, a pavement type of CJ implies that the pavement was composite and it was re-constructed as jointed concrete pavement.

Table 19
Example-guideline for PMS database continuity for possible pavement preservation categories

Existing Pavement Type	**Pavement maintained, rehabilitated, or reconstructed to**			
	CRC (CR)	Jointed (J)	Flexible (F)	Composite (C)
CRC	CRCR	CRJ	CRF	CRC
Jointed	JCR	JJ	JF	JC
Flexible	FCR	FJ	FF	-
Composite	CCR	CJ	CF	CC

Note that within each of the fifteen pavement preservation categories there is one or more pavement treatment options.

CRCR: Continuously reinforced concrete pavement reconstructed as continuously reinforced (CR) concrete pavement
CRJ: Continuously reinforced concrete pavement reconstructed as jointed (J) concrete pavement
CRF: Continuously reinforced concrete pavement reconstructed as flexible (F) pavement
CRC: Continuously reinforced concrete pavement overlaid with asphalt concrete (C) pavement (composite)

Remaining Service Life (RSL) and Uniform Pavement Sections

Determination of RSL Using 1/3rd Percentile Models

Recall the RSL of a pavement section is the estimated/predicted number of years of service from any given date (usually from the last distress survey date) to the time when the pavement section is expected to accumulate distress points equal to the threshold value. The maximum value of the RSL is the design life of the last rehabilitation or construction and the minimum value of the RSL is zero. A detailed description of concept and applications of RSL has been discussed in the literature review section of this report.

Typical roughness index (RI) as a function of surface age for a control section 008-02 of NHS is illustrated in Figure 72. The figure shows RI values for all element IDs (1/10th mile) of the control section. It can be seen that there is a significant scatter in the RI values for a given control section. This indicates that each 1/10th mile of the control section behaves differently. In order to reduce the variation, the data were divided into three zones, and regression models were fit to each zone as shown in the Figure 73. For the given control section, the models exhibited the following function:

$$RI = 100 - b \cdot SA^{a} \quad (30)$$

where, *b* and *a* are regression coefficients; *b* = 0.18, 2.28, and 4.73 for upper, middle, and lower models, respectively; and *a* = 1.56, 0.93, and 0.82 for upper, middle, and lower models, respectively.

In order to determine the RSL of the each element ID (1/10th mile) of the control section, the distress data for each surface age can be divided into three percentile groups based on any available technique. For each percentile group, respective models can be applied to the last year distress data. The previous procedure will be referred as "percentile method" in this report. However, this percentile method is somewhat complicated and time consuming. Therefore, a "simplified method" is suggested as follows:

1. Identify the last collected distress data along with the surface age for each element ID (1/10th mile) of pavement section as shown in Figure 73.
2. Identify the rehabilitation threshold index value for RSL determination.
3. Predict the distress index using the three models and current surface age for each element ID as shown in Figure 73.
4. Compare the three predicted values with the existing distress index value. Identify the model that exhibited minimum absolute difference between the predicted and current

distress index value (see Figure 74 and Table 20).

5. Shift the model upward or downward based on the current index value of the Element ID in question. Apply the model and predict the index values shown as dotted values in Figure 74.
6. Determine the surface age at which the model predicts the threshold index value $(SA)_{TH}$ as shown in Figure 74.
7. Determine the difference of the surface age at the threshold index value and the surface age of the actual current index value. This represents RSL of the element ID (see Figure 74).
8. Compare the RSL values with the design life of rehabilitation action. If the RSL value is higher than the design life of rehabilitation then the RSL is equal to the design life. Similarly, the RSL with a negative value must be assigned a value of zero.

A summary of the results for the three element IDs is shown in Table 20. The RSL values calculated from the percentile and suggested simplified methods are shown in Figure 75. It is evident from the data in Figure 75 that RSL values predicted by simplified method are in close agreement with the RSL obtained from the percentile method.

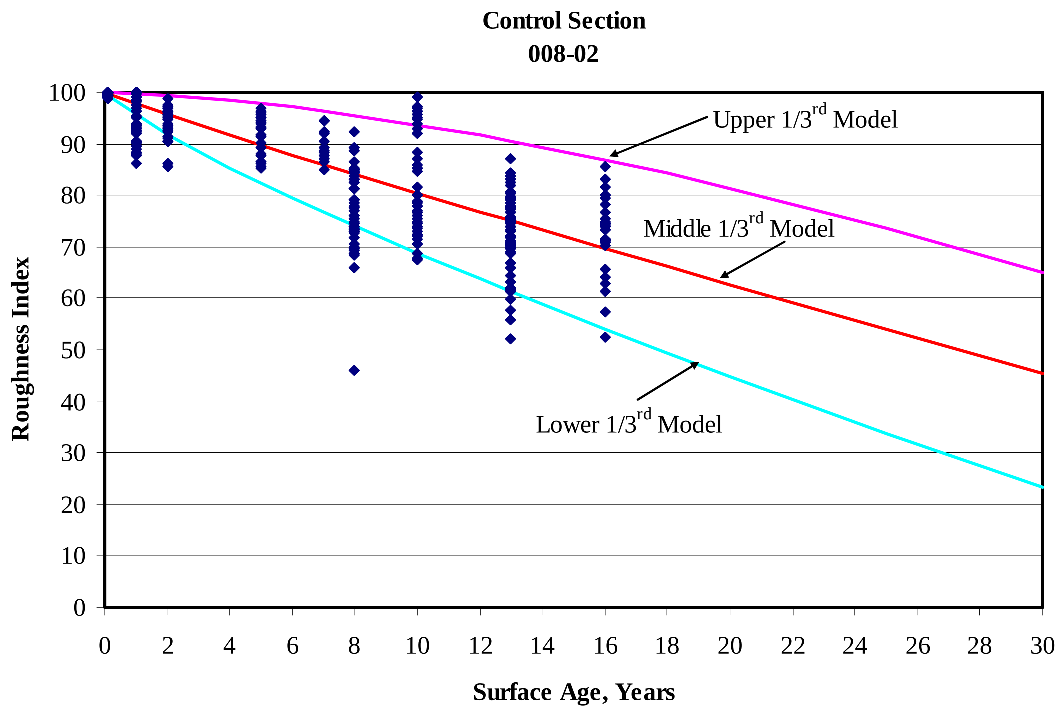


Figure 72
Typical RI as a function of surface age and associated three models for control section 008-02 NHS

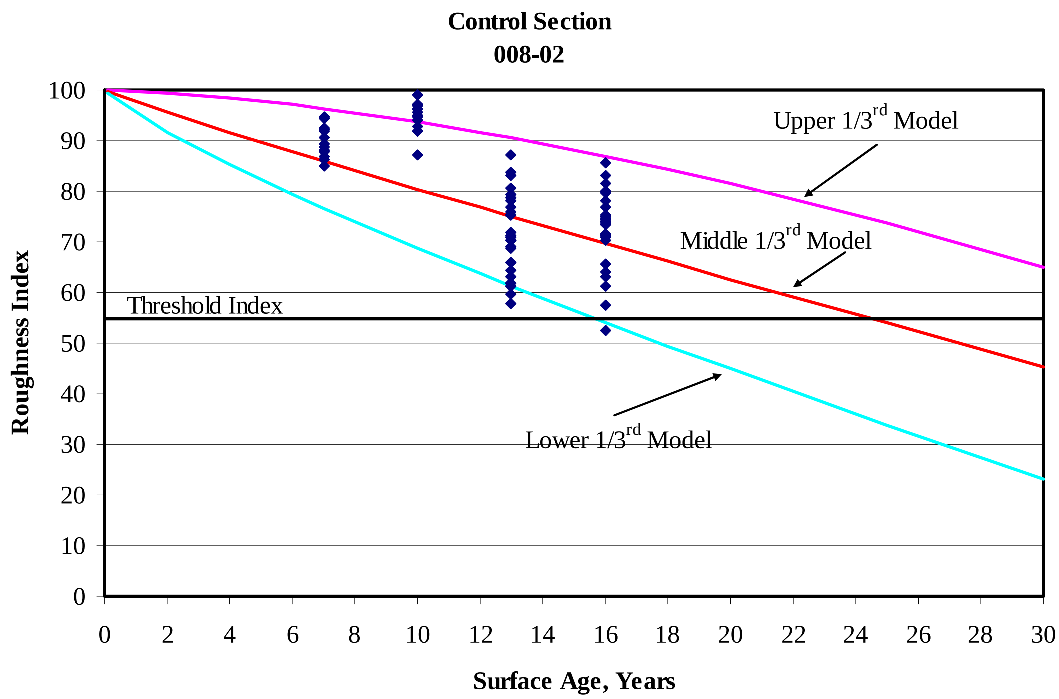


Figure 73
Typical RI plot for last year distress data as a function of surface age and associated three models for control section 008-02

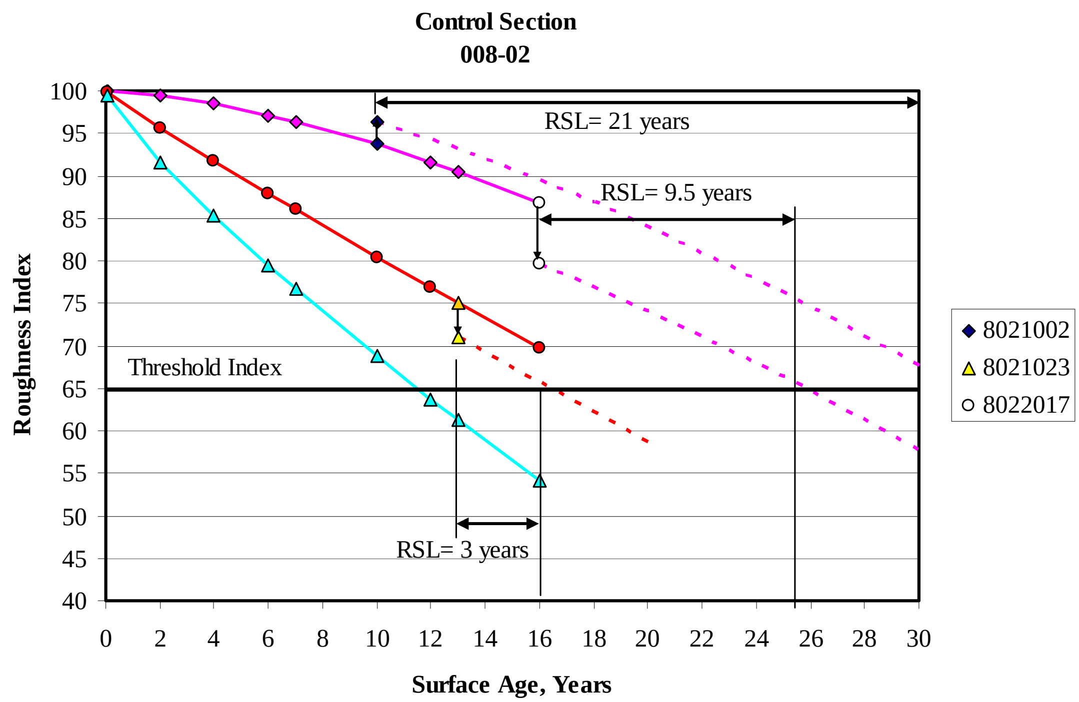


Figure 74
Illustration of RSL prediction for three selected element ID of control section 008-02

Table 20

Summary of RSL results for the three element IDs of control section 008-02

Element ID	Last Year Distress Index	SA	Predicted Distress Index			Difference Between Actual and Predicted Values			AM	Model Triggered	RSL (Years)
			L	M	U	L	M	U			
8021002	96.4	10	68.8	80.4	93.7	27.6	16.0	2.7	2.7	Upper	21.0
8021023	71.0	13	61.3	75.0	90.5	9.7	-4.0	-19.5	4.0	Middle	3.0
8022017	79.6	16	54.1	69.7	86.9	25.5	9.9	-7.3	7.3	Upper	9.5

SA: Surface age, L: Lower, M: Middle, and AM: Absolute minimum value.

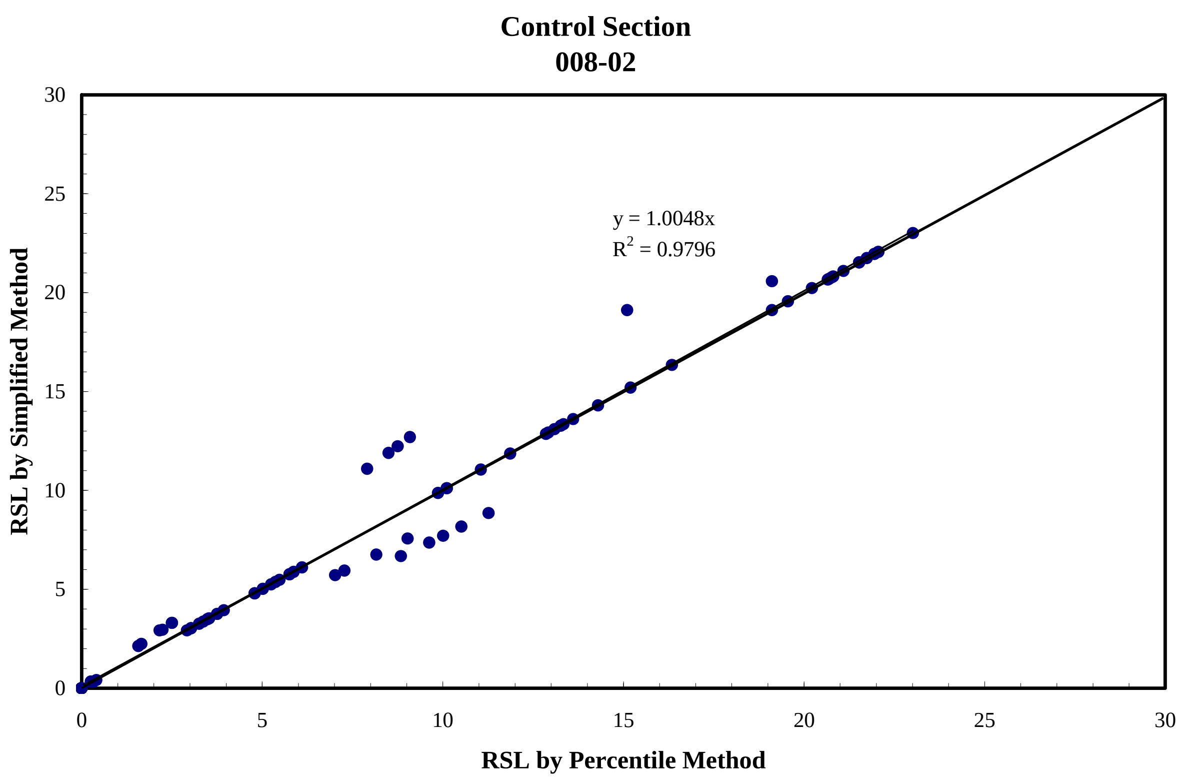


Figure 75

RSL using percentile and simplified methods for control section 008-02

RSL Distribution and Uniform Pavement Sections

From the outset, it is assumed herein that the RSL of a pavement section is calculated based on distress data or distress indices of several years. It is further assumed that the algorithm of the RSL is constrained by the design life of the pavement section in question. That is the maximum RSL of any pavement section is equal to or less than the design life of that pavement section. After calculating the RSL of each 1/10th mile pavement section along the network, the percentage of the pavement network having a certain RSL value could then be calculated and the distribution of the RSL of the pavement network can be obtained as shown in Figure 76. The RSL distribution shown in Figure 76 is the optimum desirable distribution. It should be noted that the RSL distribution shown in the figure is based on randomly selected sections of the NHS flexible pavement system. As we know, neither model used to predict the RSL of each 1/10th mile of the pavement network nor the distress data or the distress indices are one hundred percent accurate. Thus, it is desirable to divide the RSL into several categories as shown in Figure 77. The ranges of the RSL in the first two categories are smaller than the other four categories because the accuracy of the RSL decreases as its value increases. The bar chart of Figure 77 represents the percentage of the network in each uniform pavement section category based on the RSL.

Figure 78, on the other hand, shows the distribution of the RSL of each pavement type within a pavement network. The bar chart in this figure represents the uniform pavement section subcategories. Other constraints could be addressed and other figures similar to Figure 78 could be produced. For example, the data in Figure 76 could be constrained to one route such as Interstate 10 or to one route within given political boundaries, or control section. The last two or three constraints (route number, political boundaries, or control section) produce uniform pavement section candidate projects. The data could be superimposed on a map of the road in question such as that shown in Figure 79. As can be seen from the figure, uniform pavement section candidate projects may consist of one contiguous segment of the road or several segments separated by other uniform pavement section candidate projects. If the state policy allows one contract to address noncontiguous pavement segments within given political boundaries, then one uniform pavement section candidate project can be addressed in one contract. Otherwise, each pavement segment within a uniform pavement section candidate project must be contracted separately.

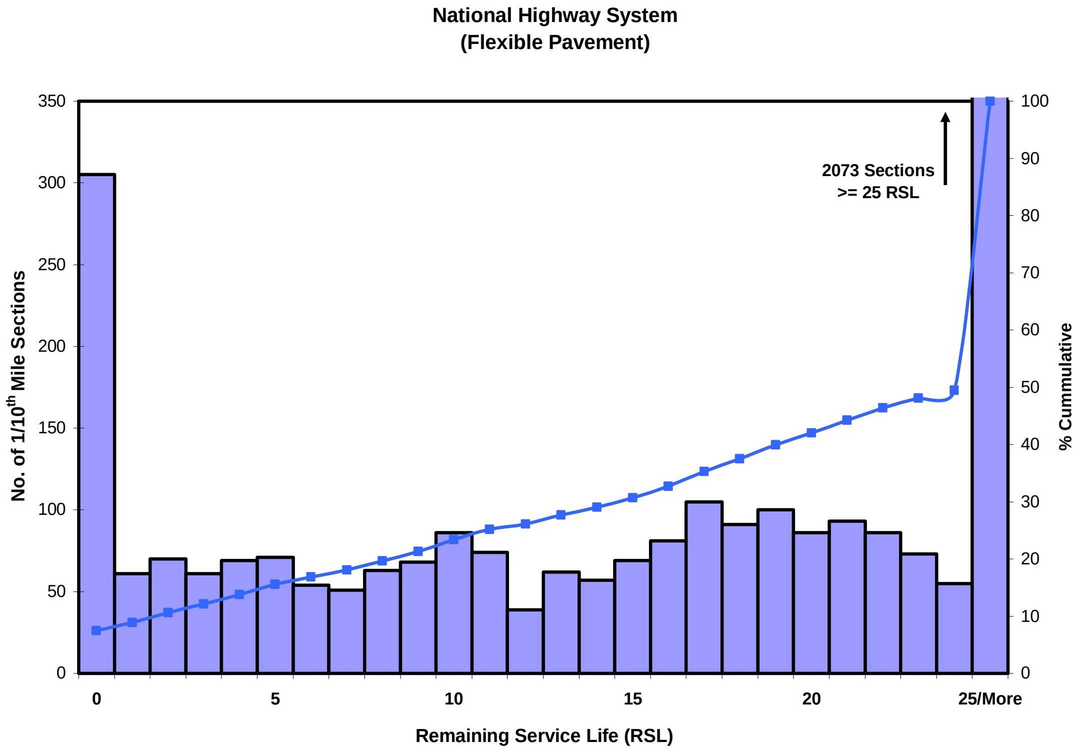


Figure 76
RSL distribution of randomly selected pavement sections of NHS flexible pavement

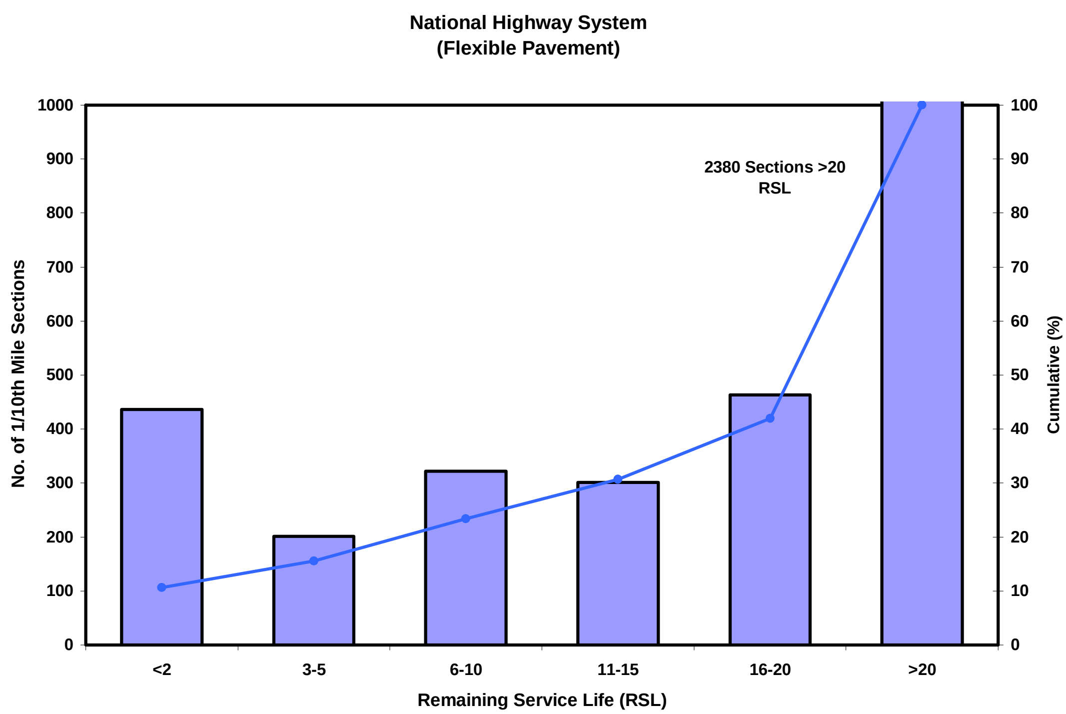


Figure 77
Uniform pavement section categories of a pavement network

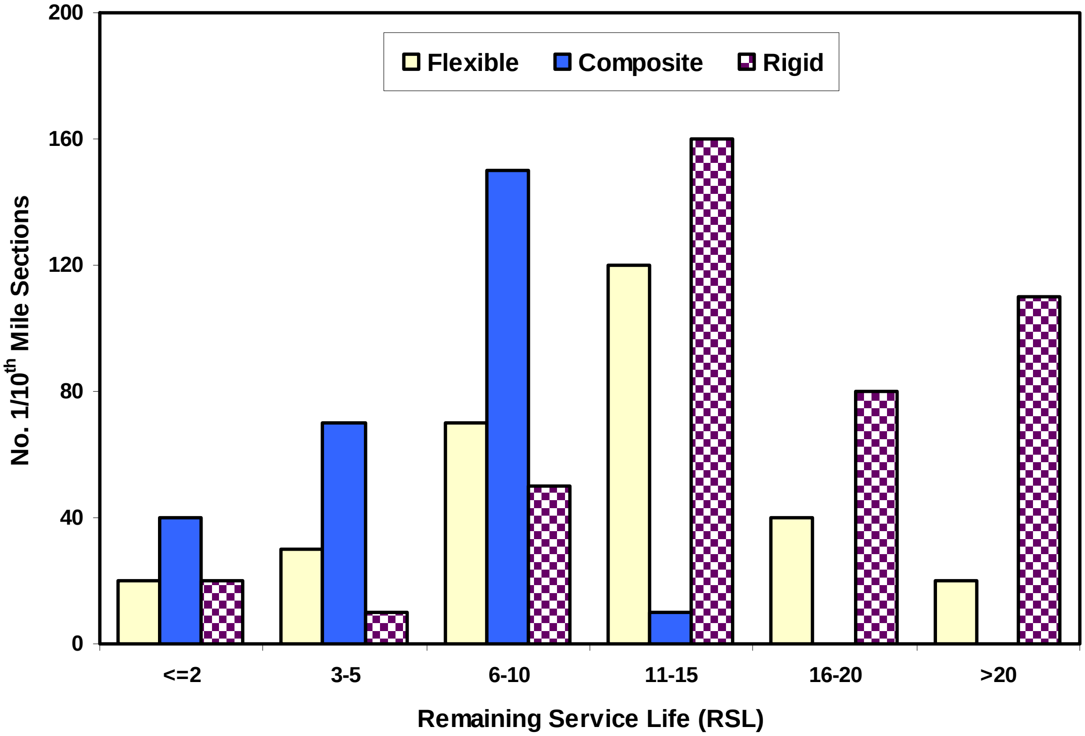


Figure 78
Typical distribution of RSL of each pavement type in a pavement network

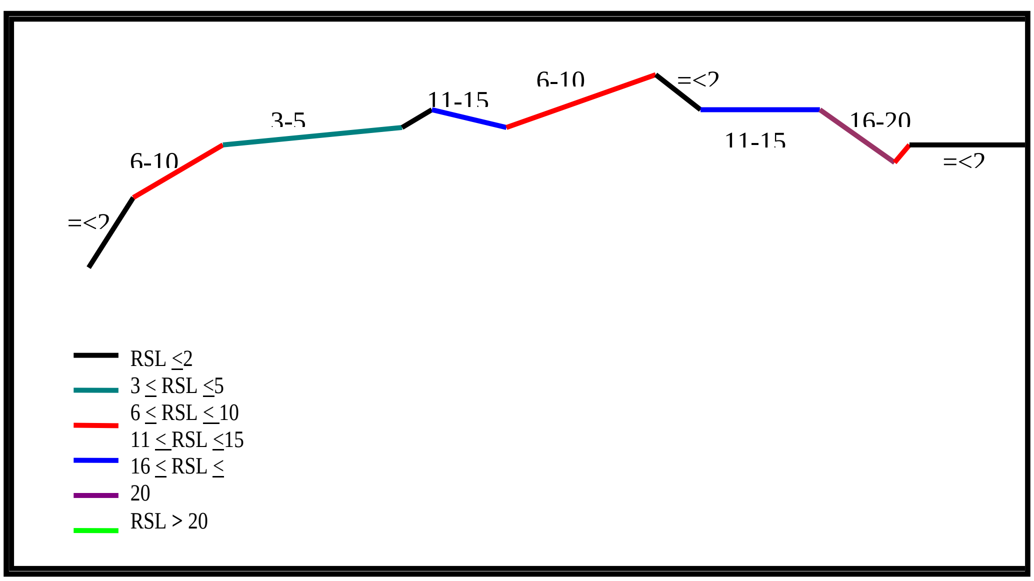


Figure 79
A strip map showing uniform pavement section candidate projects along a road within given political boundaries

Figure 80 exhibits the existing and a "do nothing" option RSL distribution of control section 008-02. It is evident that 44 percent of the control section has RSL less then or equal to 5 years and needs immediate attention. A "do nothing" option will shift the distribution towards low values of RSL, and 57 percent of the control section will need immediate maintenance and rehabilitation actions. It should be noted that the RSL of pavement sections for the control section was constrained to the design life of 20 years. Various strategies can be utilized, and the optimization of the RSL network can be performed based on budget constraints. Similar analyses can also be extended to overall pavement network health determination.

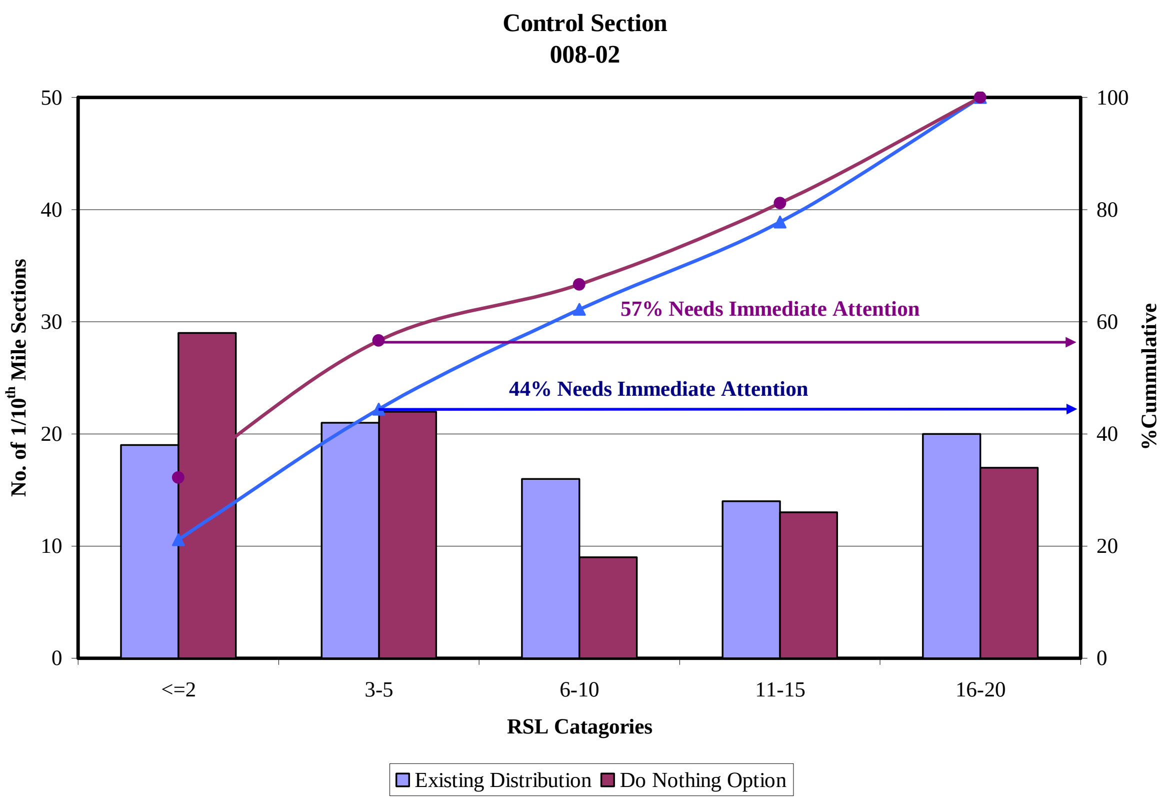


Figure 80

Existing and do nothing option RSL distribution of control section 008-02

After construction, the RSL of each uniform pavement section project should be tracked against time as shown in Figure 81 for control section 010-06 after overlay. The figure shows:

1. The RSL of the uniform pavement section project along control section 010-06 stayed uniform for the last 12 years since construction. The implication of this is that the selected rehabilitation option for that control section in 1996 provided uniform extension in the life of that pavement.

2. The RSL of the uniform pavement section project decreases 2 years for each 2 years of aging. This implies that the RSL model and the data used in the calculation of the RSL are relatively accurate.

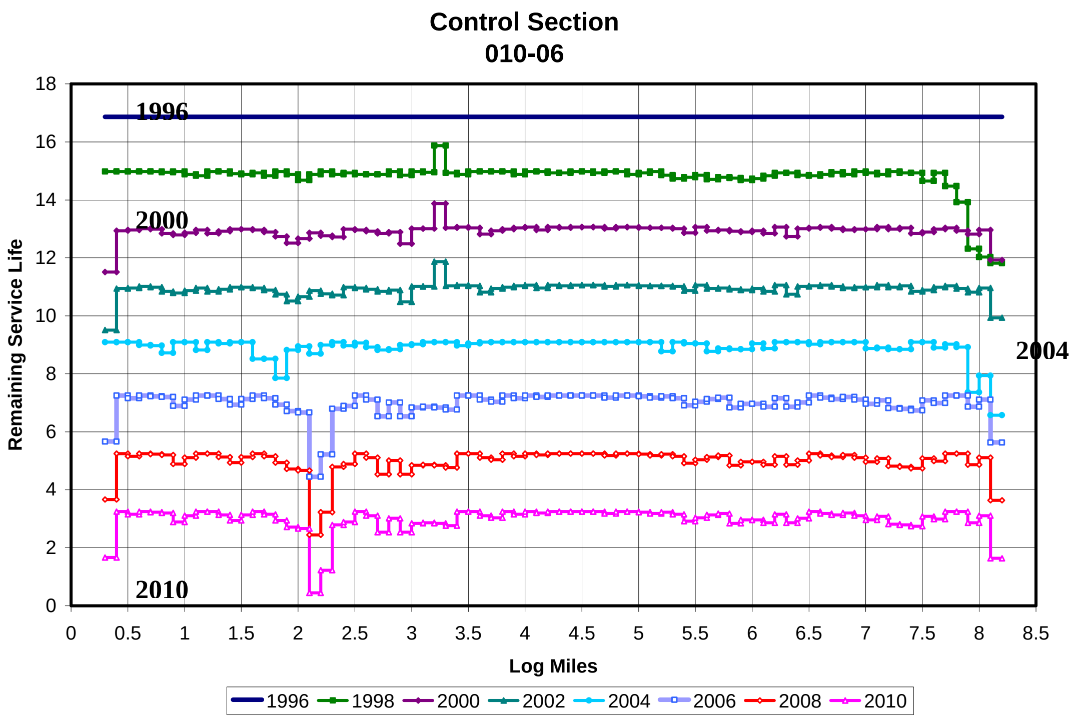


Figure 81

Progression of RSL since construction of control section 010-06

Likewise, Figure 82 shows the RSL of control section 854-10 over time. It can be seen that the conditions of the control section change drastically over time. The data in Figure 82 imply:

1. The initial RSL of the pavement section along control section 854-10 of 10.5 years was calculated based on the distress data and no constraints were included in the calculation. That is the initial RSL value was not constrained by the life expectancy of the treatment, in this case, chip seal. This can be alleviated by restricting the maximum RSL value of any pavement sections to be equal to or less than the expected life of the fix, which is likely 4 years for chip seal.

2. The RSL of the uniform pavement section project along control section 854-10 stayed uniform during the first year after construction. During the second and subsequent years, the control section appears to break-up to several segments of uniform conditions. The data could be used to determine locations where maintenance should be applied.

3. The data shown in Figure 82 may indicate that because of the high rate of deterioration the chip seal option was not the optimum fix type for control section 854-10. Perhaps it is the option used to hold the road until funds become available for a more expensive fix.

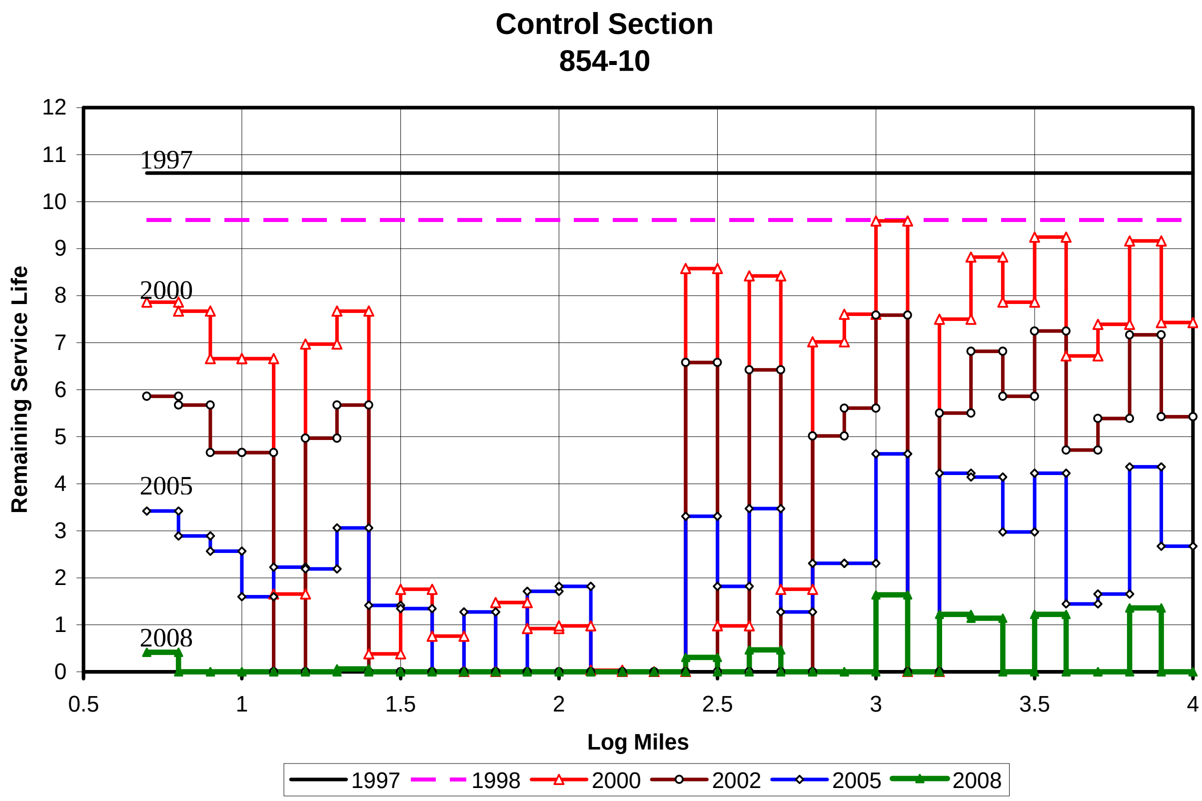


Figure 82
Progression of RSL since construction of control section 854-10

The data that are similar to those in Figures 81 and 82 could be used to study the performance of any pavement fix. However, this detailed data should not be used to select uniform pavement sections. The data should be processed in certain ranges of RSL. To illustrate, consider the data in Figure 82. If the initial RSL value was constrained to the expected life of the chip seal of 4 years and if the RSL categories of RSL $\leq$ 2 and 5 $\geq$ RSL $\geq$ 3 are used, then the data would indicate uniform sections throughout the life of the fix as shown in Figure 83. That is, in the selection of uniform pavement section candidate projects, all 1/10th mile pavement sections having RSL values within the pre-determined RSL categories should be parts of the uniform section. It is recommended that LADOTD use the six RSL categories listed in Table 21 to identify uniform pavement section categories, subcategories, and candidate projects. These categories can be modified as the estimates of the expected life of each pavement fix option become accurate.

Nevertheless, the main advantage of using the RSL to divide the network into uniform pavement sections is that all pavement segments within any uniform section would have similar pavement conditions and rate of deterioration.

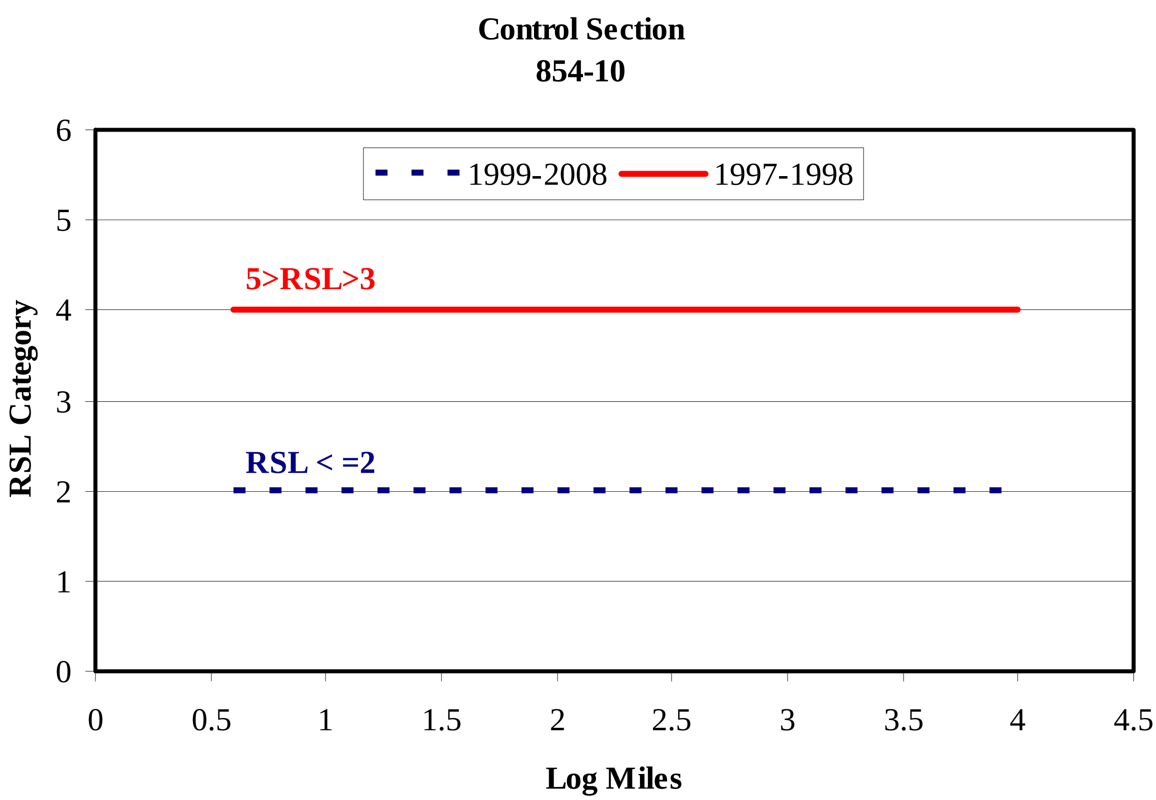


Figure 83
The uniform pavement section project, control section 854-10

Table 21
Recommended RSL categories

RSL Categories (years)
≤ 2
3 to 5
6 to 10
11 to 15
16 to 20
>20

CONCLUSIONS

Based on the comprehensive evaluation of pavement distress data in conjunction with the historical information, the following conclusions were drawn:

1. Most existing LADOTD pavement performance models were developed using the initial few years of distress data, which tends to either underpredict or overpredict the pavement condition. Pavement performance models based on available 10 years were developed that will enhance the predicting capabilities of LADOTD's PMS section.

2. Index based pavement performance models were developed for all the control sections that exhibited good performance data and historical records. The models were established for each distress type for four pavement types and four highway system classifications. Such models were classified in three categories; upper, middle, and lower $1/3^{rd}$ percentile for each control section. The results indicated that the models followed the power function and the predicted values exhibited good agreement with the actual values.

3. In order to reduce the number of the models, the developed models were clustered and consolidated based on pavement rate of deterioration. It was found that the consolidation process substantially reduced the number of models and showed good predictions with up to 90 percent data exhibiting $\pm$ 7.5 percent error between the predicted and observed values.

4. A fundamental relationship between the pavement rate of deterioration and pavement age was evaluated for various distress type, pavement type, and highway system classification. The data indicated that, with the increase in age of the pavement, the rate of deterioration increases. Based on this fundamental concept, generalized models were established for most of the distress types. The results of the analyses showed good agreement of predicted index values with the actual index values for randomly selected control sections. Furthermore, on the average, 65-90 percent of data exhibited $\pm$ 7.5% error between the predicted and actual values for all the models.

5. The types of treatments used by LADOTD are very popular and are being adopted by many state highway agencies. The treatment selection is based mainly on the values of the distress index of several distress types and does not express the pavement rate of deterioration. Furthermore, the causes of distress are not a part of treatment selection process.

6. The performances of three pavement treatments were evaluated for selected projects. Various performance models were examined that provide a good fit to the data. The results of the statistical analysis indicated that the average life for chip seal, micro-surfacing, and 2-in. overlay treatments for the selected projects were 6, 7.5, and 12.5 years, respectively.

7. The data analyses of the treatment performances showed that the condition of the pavement prior to the treatment affects the overall performance. For the same threshold index value of treatment, the pavement projects with higher indices prior to the application of the treatment exhibited better performance. The analyses of treatment life revealed that for every 5-unit increase the treatment life increased by 4 and 1.6 years for micro-surfacing and chip seal, respectively. Moreover, for the average life of micro-surfacing and 2-in. overlay treatments, the roughness threshold indices were observed to be 85 and 70, respectively.

8. The remaining service life takes into account the index value and rate of deterioration of the pavement section in question. This concept can effectively be applied not only to establish the uniform control sections but also to evaluate and optimize the pavement network condition.

RECOMMENDATIONS

Based on the comprehensive evaluation of pavement distress data in conjunction with the historical information the following recommendations were made:

1. It is recommended that the generalized pavement performance models that are developed based on the fundamental concept and actual data trend should be utilized to predict the pavement network conditions. The models are similar to the existing LADOTD family curves and can be implemented immediately. It should be noted that all the models are based on current LADOTD deduct point scheme; any changes in the deduct point policy would require recalibration of the developed models.

2. The individual pavement performance models developed for each control section and the consolidated models have better prediction capabilities relative to the generalized models. These models should be used for project level PMS analysis. However, these models may need a gradual and steady implementation plan due to the fact that the application of these models may require initial preparation and formatting of the PMS data set along with some computer logic and scheme of analysis.

3. It is recommended that in conjunction with the distress index the recommended six RSL categories be utilized to identify uniform pavement section categories, subcategories, and candidate projects. These categories can be modified as the estimates of the expected life of each pavement fix option become accurate. The main advantage of using the RSL to divide the network into uniform pavement sections is that all pavement segments within any uniform section would have a similar rate of deterioration and similar pavement conditions.

4. It is recommended to consider conducting comprehensive research studies to evaluate the following:

    a. Pavement treatment selection models based on LADOTD distress data that will facilitate accurate trigger values and a scheme for the selection of the most cost-effective pavement treatment/preservation action. It should be noted that with the approval of the Project Review Committee such analyses were not conducted by the research team due to the time constraints.

    b. Development of pavement treatment performance models for all treatment types used by LADOTD based on pavement type and highway classifications. Preliminarily analyses and evaluation using the PMS database for a few highway classifications and pavement treatments have been presented in this report.

c. Explore expanding the treatment types based on the Louisiana conditions and practices. This will allow the LADOTD to have additional rehabilitation options, which will facilitate in selecting an optimum alternative based on benefit-cost analysis.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ADF	Average duration of fix
ADM	Average distress measure
ADOT	Arizona Department of Transportation
ARAN	Automated road analyzer
ASD-	Average slope of distress
ASP	Flexible pavements
CSLM	Control Section Log Mile
COM	Composite pavements
CRC	Continuously reinforced concrete pavements
FHWA	Federal Highway Administration
FI	Fatigue cracking index
HPMA	Highway pavement management application
HIS	Interstate highway system
IRI	International roughness index
JCP	Jointed Concrete Pavement
LADOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center
LTPP	Long Term Pavement Performance
LI	Longitudinal cracking index
MEPDG	Mechanistic-empirical pavement design guide
NHS	National Highway System
PMS	Pavement Management System
PRC	Project Review Committee
PSR	Pavement serviceability rating
OPF	Overall performance factor
RMP	Route mile post
RHS	Regional Highway System
RSL	Remaining service life
RI	Roughness index
RTI	Rut index
SA	Surface age
SHA	State highway agencies
SHS	State Highway System
STA	Station number

SL	Service life
TI	Transverse cracking index
TOPS	Tracking of projects
WSDOT	Washington Department of Transportation

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APPENDIX A

Example-Model Consolidation

The alligator (fatigue) cracking on ASP SHS was selected for model consolidation. The model form chosen for this example is represented by the power function. Note the models are for each control section thus constituting a total of 595 models (Table 22). The first criterion or model selection is coefficient of determination (R^2) which must be above 0.5. Table 23 represents the R^2 for each of the control sections in 1, respectfully. In Table 23 the grayed out cells represent the models that do not pass the first criteria based on R^2. The second criterion is P-values ≤ 0.05. Table 24 represents the P-value for each of the control sections in, respectfully. In Table 24 the grayed out cells represents the models that do not pass the second criterion of P-values. Because of this, the model form is a power function the leading coefficient is always positive (third Criterion). The final criterion is that the exponent must be positive. Table 25 represents the exponents for the model in each of the control sections in 1, respectfully. Since all the numbers in Table 25 are positive, all the control sections pass the final criterion. Once all four criteria are applied, the number of models is reduced to 577.

Once the original set of data were reduced to 577 models, the model consolidation technique was applied. The coefficient "a" was grouped into 10 subgroups from 0.00 to 2.50 at an interval of 0.25 to facilitate model consolidation. The power function yielded the following form:

$$\mathrm{DP} = 10^{b} \cdot (\mathrm{SA})^{a} \tag{31}$$

where,
DP = deduct point,
SA = surface age, and
a and b = regression coefficients.

Equation 31 can be rewritten as:

$$\log(\mathrm{DP}) = b + a \cdot \log(\mathrm{SA}) \tag{32}$$

Equation (32) represents a straight line in a log-log scale with *b* as an intercept and *a* as the slope of the line. The *a* coefficient indicates the rate of deterioration of the pavement. Since the rate of deterioration is important for the pavement engineers, the coefficient *a* was used to define the 10 subgroups.

The subgroup selected for this example is 1.50 to 1.75 with 136 models (Table 26). Table 27 represents the slopes of the linear model and the exponent of the power model for control sections in Table 26, respectfully. Table 28 represents the intercepts of the linear models for control sections shown in Table 26, respectfully. Table 29 represents the leading coefficient of the power model for the same control sections. Note that the values in Table 29 are calculated by placing each value in Table 28 in the exponent position with a base of 10.

$10^{-1.963} = 0.011$ Example calculation for row 1 column 1 in Table 29

The models were reduced by examining the predicted values at the 15th year using Equation 31 with SA equal to 15. Table 30 represents the predicted value for each model at year 15 for the control sections in Table 26, respectfully. The outliers were determined by calculating the first and third quartile technique, and the outliers models were removed.

$\left(10^{b}\right)_{avg} = 0.052$ Determined by averaging all values in Table 29

$a_{avg} = 1.405$ Determined by averaging all values in Table 27

$$\text{Prediction of the Average Model} = \mathrm{P}_{\mathrm{avg}}(SA) = \left(10^{b}\right)_{avg} \cdot SA^{a_{avg}} = 0.052 \cdot 15^{1.405} = 2.34$$

Since the number of models (n) = 136, which is even, then:

$$i = \frac{n}{2} = \frac{136}{2} = 78$$

and

$x_i = 1.61$
$x_{i+1} = 1.63$ (Table 30)

So,

$$\text{Median} = Q_2 = \frac{x_i + x_{(i+1)}}{2} = \frac{1.61 + 1.63}{2} = 1.62$$

Since n = 136 is even, then:

$$l = i = 78$$

Since l = 78 is even, then:

$$j = \frac{l}{2} = \frac{78}{2} = 39$$

and

$$x_j = 0.99$$
$$x_{j+1} = 1.00$$ Table 30

So;

$$\text{First Quartile} = Q_1 = \frac{x_j + x_{(j+1)}}{2} = \frac{0.99 + 1.00}{2} = 0.995$$

$$k = i + j = 78 + 39 = 117$$

and

$$x_k = 3.57$$
$$x_{k+1} = 4.04$$ (Table 30)

Since l = 78 is even, then: (Table 30)

$$\text{Third Quartile} = Q_3 = \frac{x_k + x_{(k+1)}}{2} = \frac{3.57 + 4.04}{2} = 3.805$$

$$\text{Upper Limit} = \mathrm{P_{avg}}(SA) + 1.5 \cdot (Q_3 - Q_1) = 2.34 + 1.5 \cdot (3.805 - 0.995) = 2.34 + 7.90 = 10.24$$

$$\text{Lower Limit} = \mathrm{P_{avg}}(SA) - 1.5 \cdot (Q_3 - Q_1) = 2.34 + 1.5 \cdot (3.805 - 0.995) = 2.34 - 7.90 = -5.56$$

The values used to calculate the first, second, and third quartiles are highlighted in Table 30. Using the upper and lower limits the last four are highlighted because they are considered outliers. All this represents just the first iteration. The quartile method is completely done again for the second iteration. The iterations are completed when there are no outliers left. It should be noted MS Excel sheets were generated to perform the above analysis.

Table 22
All the control sections for alligator cracking ASP SHA

810-00	791-74	791-19	902-21	983-92	843-08	984-99	773-18	919-72	948-32	865-28	611-11	609-68	918-36
661-04	788-58	812-51	773-88	642-79	701-93	839-35	842-14	889-70	944-38	860-61	825-47	560-70	969-80
754-11	690-51	932-07	906-24	638-13	743-44	682-35	810-56	979-84	942-93	778-96	999-59	516-37	825-78
798-32	806-08	988-18	969-72	987-08	584-68	932-03	928-55	973-78	812-31	536-00	984-99	718-58	721-27
917-70	790-74	975-89	615-98	991-57	948-39	985-00	969-03	988-52	981-93	973-34	767-29	800-50	687-13
979-36	992-42	786-60	663-53	673-34	998-14	953-59	818-73	855-43	663-32	748-83	969-36	810-69	821-41
783-00	968-40	736-20	789-07	656-33	831-28	785-50	670-62	647-62	965-30	925-06	966-21	783-45	719-74
788-64	723-16	964-31	887-38	717-09	913-28	854-03	962-10	972-83	833-55	506-52	986-52	702-77	626-51
795-06	711-36	817-51	798-65	705-80	983-97	946-11	983-03	630-49	553-46	834-95	790-43	736-43	776-06
800-73	875-31	782-25	987-27	976-10	771-73	580-01	957-41	975-47	976-65	754-86	826-71	993-09	729-72
772-73	648-84	878-06	988-08	955-34	974-64	676-68	775-82	733-33	939-93	976-59	766-89	641-84	591-06
991-28	986-19	737-04	732-03	609-10	601-92	828-05	964-73	961-53	949-72	769-31	870-10	591-23	761-94
585-94	820-06	894-57	961-61	994-92	659-14	653-25	934-41	640-07	959-74	974-39	582-72	701-32	692-98
757-74	981-27	814-08	729-86	934-86	982-11	987-77	981-29	954-51	930-74	985-82	830-12	512-91	645-77
750-81	987-29	826-20	625-00	962-82	751-11	709-64	774-12	975-71	970-47	983-35	962-06	737-52	621-70
971-70	746-41	730-46	771-85	916-21	679-54	699-88	820-86	730-36	894-01	969-62	989-84	979-92	697-32
881-25	994-06	919-55	972-76	759-49	602-75	617-80	977-46	633-79	705-20	964-39	982-77	816-66	739-69
774-69	785-58	585-42	975-17	690-59	784-24	756-15	963-54	744-41	969-37	983-45	994-29	796-19	787-20
778-85	635-25	978-99	981-76	797-84	974-09	950-54	703-80	982-97	863-22	980-48	981-36	783-01	162-32
774-76	622-72	981-36	940-31	731-59	717-75	771-99	975-77	864-68	712-13	966-85	625-25	736-47	307-76
971-74	609-62	997-59	875-49	652-50	721-14	839-86	938-87	579-97	575-93	990-09	707-56	695-88	497-06
969-05	834-99	835-10	980-71	787-25	945-30	943-70	823-79	710-96	851-98	857-31	806-26	705-40	440-77
727-76	762-74	827-69	887-95	680-23	796-63	964-48	848-69	640-68	936-89	607-46	953-71	619-17	389-56
749-28	844-24	744-79	760-55	970-09	658-81	979-35	800-34	750-05	973-91	908-40	983-10	797-27	485-54
713-97	671-58	791-38	959-14	985-24	900-54	901-51	822-71	535-87	607-95	581-04	974-77	726-70	221-56
683-12	725-62	806-81	964-73	951-24	961-11	831-86	970-99	981-67	887-88	704-54	967-96	708-80	220-23
950-31	750-86	969-46	838-14	809-89	885-70	981-56	970-77	791-94	794-86	638-34	978-12	715-15	466-36
988-05	797-47	988-34	553-69	938-79	874-89	955-91	868-92	938-81	704-36	686-86	869-33	756-79	478-70
965-50	869-19	936-63	606-55	627-42	669-16	802-43	800-35	896-28	816-18	972-58	936-72	751-29	300-36
839-44	623-65	928-15	778-59	677-32	977-74	962-55	963-46	978-81	695-47	813-65	588-53	727-03	332-36
678-91	822-71	781-12	964-68	978-39	835-15	778-07	764-72	933-93	818-87	871-73	777-96	820-62	303-31
777-58	724-58	975-36	967-83	903-15	871-49	747-22	937-00	892-96	959-29	935-93	551-74	751-36	492-73
829-05	957-66	857-16	863-26	730-96	872-89	863-93	672-41	865-06	969-80	974-26	513-68	677-78	420-16
589-97	614-36	847-44	944-33	983-60	721-51	814-61	755-53	770-64	655-77	641-65	719-57	667-37	463-91
702-40	906-92	969-07	643-03	837-47	973-13	975-00	990-33	786-25	950-96	708-55	510-15	735-61	253-11
846-73	852-21	964-78	605-49	634-10	958-32	996-13	793-59	966-16	916-43	712-77	757-86	780-98	278-06
576-77	705-43	852-70	971-24	780-51	926-20	965-57	686-84	819-63	536-12	854-10	658-98	821-01	-
646-13	772-66	709-64	693-19	935-26	866-85	775-98	739-91	756-99	963-65	762-69	603-94	813-50	-
737-59	827-19	699-16	969-83	820-76	760-35	821-45	728-00	899-97	601-81	973-97	776-46	711-95	-
975-31	981-05	749-96	979-01	720-86	814-86	985-23	990-39	856-03	987-64	896-50	754-27	746-32	-
984-18	654-44	657-45	986-50	950-21	967-72	985-10	953-82	973-14	956-34	705-14	751-37	707-98	-
858-73	627-75	880-63	841-23	983-56	967-89	989-30	645-77	965-11	545-88	700-81	692-70	646-45	-
651-68	666-52	784-87	930-73	976-35	945-45	911-43	961-71	983-35	765-62	735-48	681-26	834-23	-

Table 23
All the R-square values for the control sections in Table 22

0.810	0.792	0.791	0.902	0.984	0.843	0.985	0.773	0.920	0.948	0.865	0.611	0.610	0.918
0.661	0.789	0.813	0.774	0.643	0.702	0.839	0.842	0.890	0.944	0.861	0.825	0.561	0.970
0.754	0.691	0.932	0.906	0.638	0.743	0.682	0.811	0.980	0.943	0.779	1.000	0.516	0.826
0.798	0.806	0.988	0.970	0.987	0.585	0.932	0.929	0.974	0.812	0.536	0.985	0.719	0.721
0.918	0.791	0.976	0.616	0.992	0.948	0.985	0.969	0.989	0.982	0.973	0.767	0.801	0.687
0.979	0.992	0.787	0.664	0.673	0.998	0.954	0.819	0.855	0.663	0.749	0.969	0.811	0.821
0.783	0.968	0.736	0.789	0.656	0.831	0.785	0.671	0.648	0.965	0.925	0.966	0.783	0.720
0.789	0.723	0.964	0.887	0.717	0.913	0.854	0.962	0.973	0.834	0.507	0.987	0.703	0.627
0.795	0.711	0.818	0.799	0.706	0.984	0.946	0.983	0.630	0.553	0.835	0.790	0.736	0.776
0.801	0.875	0.782	0.987	0.976	0.772	0.580	0.957	0.975	0.977	0.755	0.827	0.993	0.730
0.773	0.649	0.878	0.988	0.955	0.975	0.677	0.776	0.733	0.940	0.977	0.767	0.642	0.591
0.991	0.986	0.737	0.732	0.609	0.602	0.828	0.965	0.962	0.950	0.769	0.870	0.591	0.762
0.586	0.820	0.895	0.962	0.995	0.659	0.653	0.934	0.640	0.960	0.974	0.583	0.701	0.693
0.758	0.981	0.814	0.730	0.935	0.982	0.988	0.981	0.955	0.931	0.986	0.830	0.513	0.646
0.751	0.987	0.826	0.625	0.963	0.751	0.710	0.774	0.976	0.970	0.983	0.962	0.738	0.622
0.972	0.746	0.730	0.772	0.916	0.680	0.700	0.821	0.730	0.894	0.970	0.990	0.980	0.697
0.881	0.994	0.920	0.973	0.759	0.603	0.618	0.977	0.634	0.705	0.964	0.983	0.817	0.740
0.775	0.786	0.585	0.975	0.691	0.784	0.756	0.964	0.744	0.969	0.983	0.994	0.796	0.787
0.779	0.635	0.979	0.982	0.798	0.974	0.951	0.704	0.983	0.863	0.980	0.981	0.783	0.162
0.775	0.623	0.981	0.940	0.732	0.718	0.772	0.976	0.865	0.712	0.967	0.625	0.736	0.308
0.972	0.610	0.998	0.875	0.652	0.721	0.840	0.939	0.580	0.576	0.990	0.708	0.696	0.497
0.969	0.835	0.835	0.981	0.787	0.945	0.944	0.824	0.711	0.852	0.857	0.806	0.705	0.441
0.728	0.763	0.828	0.888	0.680	0.797	0.964	0.849	0.641	0.937	0.607	0.954	0.619	0.390
0.749	0.844	0.745	0.761	0.970	0.659	0.979	0.800	0.750	0.974	0.908	0.983	0.797	0.486
0.714	0.672	0.791	0.959	0.985	0.901	0.902	0.823	0.536	0.608	0.581	0.975	0.727	0.222
0.683	0.726	0.807	0.965	0.951	0.961	0.832	0.971	0.982	0.888	0.705	0.968	0.709	0.220
0.950	0.751	0.969	0.838	0.810	0.886	0.982	0.971	0.792	0.795	0.638	0.978	0.715	0.466
0.988	0.797	0.988	0.554	0.939	0.875	0.956	0.869	0.939	0.704	0.687	0.869	0.757	0.479
0.966	0.869	0.937	0.607	0.627	0.669	0.802	0.800	0.896	0.816	0.973	0.937	0.751	0.300
0.839	0.624	0.928	0.779	0.677	0.978	0.963	0.963	0.979	0.695	0.814	0.589	0.727	0.332
0.679	0.823	0.781	0.965	0.978	0.835	0.778	0.765	0.934	0.819	0.872	0.778	0.821	0.303
0.778	0.725	0.975	0.968	0.903	0.871	0.747	0.937	0.893	0.959	0.936	0.552	0.751	0.493
0.829	0.958	0.857	0.863	0.731	0.873	0.864	0.672	0.865	0.970	0.974	0.514	0.678	0.420
0.590	0.614	0.847	0.944	0.984	0.722	0.815	0.756	0.771	0.656	0.642	0.720	0.667	0.464
0.702	0.907	0.969	0.643	0.837	0.973	0.975	0.990	0.786	0.951	0.709	0.510	0.736	0.253
0.847	0.852	0.965	0.605	0.634	0.958	0.996	0.794	0.966	0.916	0.713	0.758	0.781	0.278
0.577	0.705	0.853	0.971	0.781	0.926	0.966	0.687	0.820	0.536	0.854	0.659	0.821	-
0.646	0.773	0.710	0.693	0.935	0.867	0.776	0.740	0.757	0.964	0.763	0.604	0.814	-
0.738	0.827	0.699	0.970	0.821	0.760	0.821	0.728	0.900	0.602	0.974	0.776	0.712	-
0.975	0.981	0.750	0.979	0.721	0.815	0.985	0.990	0.856	0.988	0.896	0.754	0.746	-
0.984	0.654	0.657	0.987	0.950	0.968	0.985	0.954	0.973	0.956	0.705	0.751	0.708	-
0.859	0.628	0.881	0.841	0.984	0.968	0.989	0.646	0.965	0.546	0.701	0.693	0.646	-
0.652	0.667	0.785	0.931	0.976	0.945	0.911	0.962	0.983	0.766	0.735	0.681	0.834	-

Table 24
All the P-values for the control sections in Table 23

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

Table 25
All the exponents *a* for the power models for control sections in Table 22

2.327	1.908	1.942	1.723	1.638	1.560	1.642	1.726	1.688	1.321	1.500	1.382	1.209	0.847
2.122	1.996	1.944	1.677	1.650	1.642	1.676	1.737	1.689	1.291	1.432	1.403	1.073	0.855
2.020	1.895	1.757	1.704	1.530	1.564	1.687	1.710	1.686	1.477	1.357	1.303	1.217	0.856
2.164	1.857	1.854	1.712	1.685	1.542	1.558	1.562	1.710	1.448	1.388	1.260	1.085	0.972
2.025	1.772	1.953	1.599	1.579	1.570	1.679	1.628	1.538	1.421	1.486	1.444	1.249	0.880
2.022	1.889	1.904	1.612	1.734	1.601	1.640	1.659	1.746	1.428	1.436	1.498	1.210	0.711
2.153	1.767	1.812	1.549	1.743	1.531	1.573	1.620	1.709	1.479	1.429	1.349	1.162	0.667
2.109	1.784	1.840	1.616	1.736	1.645	1.659	1.652	1.506	1.491	1.319	1.263	1.240	0.596
2.208	1.849	1.949	1.636	1.639	1.678	1.619	1.720	1.671	1.411	1.411	1.358	1.191	0.687
2.075	1.787	1.971	1.583	1.662	1.670	1.714	1.601	1.706	1.379	1.491	1.496	1.237	0.667
2.145	1.814	1.846	1.560	1.718	1.747	1.633	1.637	1.646	1.316	1.480	1.462	1.177	0.711
2.023	1.837	1.794	1.533	1.656	1.543	1.688	1.705	1.708	1.295	1.388	1.397	1.208	0.720
2.156	1.819	1.895	1.502	1.531	1.599	1.512	1.553	1.719	1.446	1.461	1.323	1.118	0.672
2.156	1.879	1.869	1.616	1.654	1.642	1.706	1.579	1.703	1.444	1.462	1.259	1.086	0.713
2.031	1.984	1.904	1.552	1.675	1.711	1.553	1.556	1.650	1.487	1.408	1.317	1.060	0.649
2.037	1.923	1.901	1.502	1.632	1.517	1.546	1.718	1.568	1.373	1.486	1.383	1.231	0.611
2.010	1.983	1.757	1.638	1.730	1.529	1.506	1.557	1.659	1.327	1.434	1.448	1.229	0.716
2.103	1.899	1.835	1.578	1.565	1.500	1.540	1.653	1.575	1.488	1.343	1.300	1.214	0.705
2.052	1.779	1.862	1.729	1.704	1.688	1.633	1.509	1.677	1.473	1.354	1.439	0.816	2.007
2.066	1.904	1.824	1.547	1.677	1.570	1.715	1.699	1.644	1.446	1.492	1.282	0.906	2.563
1.995	1.903	1.896	1.581	1.550	1.509	1.711	1.699	1.526	1.257	1.368	1.333	0.778	1.623
1.836	1.765	1.877	1.565	1.714	1.728	1.623	1.721	1.674	1.266	1.446	1.341	0.954	0.958
1.804	1.911	1.778	1.681	1.601	1.723	1.524	1.737	1.394	1.436	1.461	1.313	0.843	0.768
1.800	1.786	1.846	1.585	1.736	1.554	1.580	1.580	1.453	1.365	1.485	1.362	0.810	0.853
1.951	1.830	1.689	1.540	1.598	1.506	1.608	1.532	1.447	1.468	1.448	1.455	0.961	0.652
1.835	1.829	1.714	1.572	1.724	1.679	1.658	1.682	1.481	1.412	1.489	1.404	0.927	0.687
1.860	1.772	1.626	1.655	1.647	1.535	1.671	1.538	1.488	1.277	1.480	1.297	0.994	1.458
1.752	1.915	1.607	1.560	1.671	1.593	1.596	1.599	1.470	1.348	1.391	1.324	0.813	1.273
1.851	1.808	1.715	1.610	1.605	1.729	1.725	1.713	1.491	1.476	1.409	1.463	0.895	0.970
1.962	1.998	1.567	1.638	1.727	1.709	1.625	1.720	1.489	1.500	1.296	1.115	0.759	0.905
1.804	1.768	1.584	1.700	1.667	1.722	1.653	1.584	1.471	1.483	1.324	1.090	0.803	0.984
1.839	1.827	1.717	1.660	1.514	1.655	1.711	1.503	1.411	1.394	1.471	1.234	0.826	1.697
1.779	1.821	1.619	1.658	1.633	1.650	1.565	1.564	1.455	1.478	1.419	1.242	0.838	1.049
1.987	1.945	1.571	1.625	1.749	1.610	1.542	1.644	1.439	1.371	1.373	1.230	0.779	1.232
1.761	1.920	1.653	1.729	1.713	1.723	1.536	1.741	1.460	1.287	1.301	1.027	0.981	0.782
1.783	1.811	1.727	1.599	1.700	1.612	1.510	1.733	1.463	1.378	1.287	1.099	0.843	0.702
1.767	1.805	1.677	1.633	1.566	1.648	1.517	1.586	1.284	1.459	1.484	1.166	0.770	-
1.800	1.995	1.673	1.574	1.554	1.665	1.661	1.621	1.463	1.394	1.299	1.216	0.761	-
1.919	1.775	1.629	1.656	1.675	1.727	1.540	1.687	1.472	1.320	1.331	1.153	0.923	-
1.762	1.752	1.658	1.514	1.524	1.710	1.581	1.731	1.468	1.410	1.483	1.146	0.880	-
1.952	1.961	1.550	1.545	1.548	1.594	1.669	1.686	1.426	1.359	1.468	1.131	0.863	-
1.943	1.772	1.650	1.750	1.550	1.626	1.562	1.729	1.395	1.404	1.480	1.139	0.899	-
1.928	1.870	1.671	1.667	1.730	1.632	1.732	1.616	1.356	1.384	1.464	1.196	0.792	-

Table 26
Control sections for subgroup of "a" coefficient of 1.50 to 1.75

203-01	156-02	380-02	036-06	392-01	269-08	297-03	158-01	157-02	207-08	057-07	215-01	035-02	048-03
263-01	082-30	129-01	056-07	132-03	214-01	219-30	161-06	053-03	040-03	208-02	157-04	042-04	192-01
414-03	149-05	157-01	070-05	232-30	055-02	167-02	208-01	211-02	861-03	030-04	388-03	270-05	008-07
262-30	206-01	837-15	839-17	211-04	219-07	395-01	238-01	395-04	114-01	134-01	259-01	154-02	151-02
161-03	220-02	170-01	196-03	112-02	037-01	092-03	033-03	395-02	268-01	070-06	860-08	077-02	028-04
193-03	377-02	395-03	058-04	203-02	228-06	055-01	177-03	139-07	125-04	194-07	243-02	239-31	133-01
334-02	277-03	041-03	055-03	353-03	269-03	021-02	203-03	113-03	155-01	147-03	133-03	263-05	-
830-08	293-03	112-05	353-01	154-01	840-43	009-01	028-05	029-05	255-02	132-01	035-01	144-01	-
130-02	232-31	853-27	269-02	178-02	216-01	849-21	258-01	845-02	027-02	201-03	041-01	147-04	-
172-30	332-03	284-01	263-06	319-30	141-03	154-03	061-04	207-05	204-02	319-01	263-04	217-02	-

Table 27
Slopes for linear model form and exponents for power model form for subgroup 1.50 to 1.75

1.319	1.371	1.323	1.439	1.317	1.464	1.444	1.394	1.378	1.462	1.477	1.492	1.455	1.468
1.287	1.411	1.373	1.291	1.473	1.354	1.485	1.410	1.426	1.463	1.486	1.459	1.472	1.357
1.282	1.348	1.287	1.428	1.480	1.356	1.359	1.408	1.434	1.463	1.489	1.259	1.382	1.394
1.301	1.388	1.341	1.313	1.343	1.461	1.383	1.409	1.439	1.444	1.266	1.373	1.483	1.476
1.320	1.448	1.404	1.436	1.316	1.460	1.379	1.471	1.448	1.483	1.479	1.324	1.491	1.488
1.388	1.397	1.300	1.448	1.411	1.489	1.395	1.500	1.436	1.487	1.486	1.324	1.296	1.446
1.358	1.403	1.463	1.321	1.462	1.480	1.447	1.491	1.446	1.478	1.412	1.257	1.299	-
1.333	1.260	1.295	1.496	1.500	1.362	1.453	1.470	1.491	1.471	1.488	1.411	1.468	-
1.327	1.391	1.297	1.468	1.432	1.368	1.404	1.419	1.455	1.481	1.429	1.284	1.277	-
1.384	1.263	1.303	1.331	1.349	1.365	1.394	1.421	1.461	1.480	1.498	1.484	1.446	-

Table 28
Model intercepts for linear form for subgroup 1.50 to 1.75

-1.963	-1.838	-1.687	-1.749	-1.530	-1.669	-1.609	-1.467	-1.404	-1.418	-1.381	-1.364	-1.007	-0.871
-1.905	-1.884	-1.710	-1.572	-1.712	-1.539	-1.656	-1.480	-1.456	-1.412	-1.384	-1.286	-0.974	-0.715
-1.873	-1.805	-1.604	-1.715	-1.720	-1.537	-1.486	-1.469	-1.456	-1.406	-1.384	-1.038	-0.868	-0.569
-1.878	-1.849	-1.664	-1.570	-1.546	-1.659	-1.508	-1.468	-1.445	-1.379	-1.121	-1.161	-0.985	-0.609
-1.862	-1.901	-1.720	-1.707	-1.513	-1.655	-1.496	-1.540	-1.444	-1.425	-1.371	-1.100	-0.990	-0.607
-1.932	-1.811	-1.598	-1.720	-1.614	-1.686	-1.488	-1.565	-1.427	-1.407	-1.377	-1.022	-0.746	-0.227
-1.876	-1.808	-1.789	-1.563	-1.672	-1.673	-1.544	-1.549	-1.421	-1.396	-1.289	-0.926	-0.745	-
-1.843	-1.640	-1.592	-1.766	-1.716	-1.530	-1.550	-1.521	-1.472	-1.388	-1.377	-1.053	-0.908	-
-1.801	-1.793	-1.591	-1.730	-1.637	-1.526	-1.486	-1.457	-1.423	-1.398	-1.301	-0.876	-0.661	-
-1.853	-1.637	-1.593	-1.566	-1.535	-1.521	-1.468	-1.459	-1.423	-1.385	-1.372	-1.084	-0.850	-

Table 29
Leading coefficient for subgroup 1.50 to 1.75

0.011	0.015	0.021	0.018	0.030	0.021	0.025	0.034	0.039	0.038	0.042	0.043	0.098	0.135
0.012	0.013	0.020	0.027	0.019	0.029	0.022	0.033	0.035	0.039	0.041	0.052	0.106	0.193
0.013	0.016	0.025	0.019	0.019	0.029	0.033	0.034	0.035	0.039	0.041	0.092	0.136	0.270
0.013	0.014	0.022	0.027	0.028	0.022	0.031	0.034	0.036	0.042	0.076	0.069	0.103	0.246
0.014	0.013	0.019	0.020	0.031	0.022	0.032	0.029	0.036	0.038	0.043	0.079	0.102	0.247
0.012	0.015	0.025	0.019	0.024	0.021	0.033	0.027	0.037	0.039	0.042	0.095	0.180	0.593
0.013	0.016	0.016	0.027	0.021	0.021	0.029	0.028	0.038	0.040	0.051	0.119	0.180	-
0.014	0.023	0.026	0.017	0.019	0.029	0.028	0.030	0.034	0.041	0.042	0.089	0.124	-
0.016	0.016	0.026	0.019	0.023	0.030	0.033	0.035	0.038	0.040	0.050	0.133	0.218	-
0.014	0.023	0.026	0.027	0.029	0.030	0.034	0.035	0.038	0.041	0.042	0.082	0.141	-

Table 30
Predicted deduct points (x_i) at 15 years for subgroup 1.50 to 1.75

0.39	0.59	0.74	0.88	1.05	1.13	1.23	1.49	1.64	2.00	2.27	2.46	5.05	7.16
0.41	0.60	0.80	0.88	1.05	1.13	1.23	1.51	1.66	2.03	2.31	2.69	5.72	7.60
0.43	0.60	0.81	0.92	1.05	1.14	1.29	1.54	1.70	2.07	2.33	2.77	5.72	11.78
0.45	0.61	0.82	0.94	1.08	1.14	1.32	1.54	1.77	2.09	2.34	2.84	5.74	13.42
0.49	0.63	0.85	0.96	1.08	1.15	1.34	1.55	1.82	2.09	2.34	2.87	5.79	13.90
0.50	0.68	0.85	0.96	1.11	1.16	1.42	1.58	1.83	2.20	2.35	3.43	6.01	29.81
0.52	0.70	0.85	0.98	1.11	1.17	1.44	1.60	1.90	2.20	2.36	3.57	6.05	-
0.53	0.70	0.85	0.99	1.11	1.18	1.44	1.61	1.91	2.20	2.36	4.04	6.58	-
0.58	0.70	0.86	0.99	1.11	1.21	1.46	1.63	1.94	2.20	2.40	4.30	6.93	-
0.59	0.70	0.87	1.00	1.13	1.22	1.48	1.63	1.97	2.26	2.45	4.58	7.09	-

Table 31
Number (*l*) of predicted deduct point at 15 years for subgroup 1.50 to 1.75

1	11	21	31	41	51	61	71	81	91	101	111	121	131
2	12	22	32	42	52	62	72	82	92	102	112	122	132
3	13	23	33	43	53	63	73	83	93	103	113	123	133
4	14	24	34	44	54	64	74	84	94	104	114	124	134
5	15	25	35	45	55	65	75	85	95	105	115	125	135
6	16	26	36	46	56	66	76	86	96	106	116	126	136
7	17	27	37	47	57	67	77	87	97	107	117	127	-
8	18	28	38	48	58	68	78	88	98	108	118	128	-
9	19	29	39	49	59	69	79	89	99	109	119	129	-
10	20	30	40	50	60	70	80	90	100	110	120	130	-

APPENDIX B

Individual Pavement Performance Models for Control Sections

(See attached CD)

APPENDIX C

Consolidated Pavement Performance Models

(See attached CD)

APPENDIX D

Generalized Pavement Performance Models

(See attached CD)

APPENDIX E

LADOTD's Deduct Points and Pavement Treatment Selection Models

Table 32
Pavement management deduct points

ALLIGATOR CRACKING DEDUCTS						
	EXTENT (SQ.FT.)					
SEVERITY	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	43-61	61

PATCHING DEDUCTS (FOR FLEXIBLE AND COMPOSITE)							
	EXTENT (SQ.FT.)						
SEVERITY	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

PATCHING DEDUCTS (FOR JCP AND CRC)							
	EXTENT (SQ.FT.)						
SEVERITY	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

RANDOM CRACKING DEDUCTS (FOR FLEXIBLE)						
	EXTENT (LIN FT.)					
SEVERITY	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

RANDOM CRACKING DEDUCTS (FOR COMPOSITE)						
	EXTENT (LIN FT.)					
SEVERITY	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 32
Pavement management deduct points (continued)

TRANSVERSE CRACKING DEDUCTS (FOR JCP)						
	EXTENT (LIN FT.)					
SEVERITY	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

LONGITUDINAL CRACKING DEDUCTS (FOR JCP AND CRC)						
	EXTENT (LIN FT.)					
SEVERITY	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 33
Formulas for random cracking and indexes

COMPOSITE AND FLEXIBLE PAVEMENTS	
RNDM_L = LNGCRK_L + TRNCRK_L + BLKCRK_L RNDM_M= LNGCRK_M + TRNCRK_M + BLKCRK_M RNDM_H = LNGCRK_H + TRNCRK_H + BLKCRK_H	
STANDARD INDEXES	
TRAN = MIN (100 , MAX (0 , 100 – TRNCRK_L DEDUCT – TRNCRK_M DEDUCT – TRNCRK_H DEDUCT)) LONG = MIN (100 , MAX (0 , 100 – LNGCRK_L DEDUCT – LNGCRK_M DEDUCT – LNGCRK_H DEDUCT)) RNDM = MIN (100 , MAX (0 , 100 – RNDM_L DEDUCT – RNDM_M DEDUCT – RNDM_H DEDUCT)) ALCR = MIN (100 , MAX (0 , 100 - ALGCRK_L DEDUCT - ALGCRK_M DEDUCT - ALGCRK_H DEDUCT)) PTCH = MIN (100 , MAX (0 , 100 - PATCH_L DEDUCT – PATCH_M DEDUCT - PATCH_H DEDUCT))	
COMPOSITE INDEXES	
Flexible	MAX(MIN(RNDM, ALCR, PTCH, RUFF, RUT),[AVG(RNDM, ALCR, PTCH, RUFF, RUT)-0.85 STD(RNDM, ALCR, PTCH, RUFF, RUT)])
Composite	MAX(MIN(RNDM, ALCR, PTCH, RUFF, RUT), [AVG(RNDM, ALCR, PTCH, RUFF, RUT) - 0.85 STD(RNDM, ALCR, PTCH, RUFF, RUT)])
Jointed	MAX(MIN(LONG, TRAN, PTCH, RUFF), [AVG(LONG, TRAN, PTCH, RUFF) – 0.85 STD(LONG, TRAN, PTCH, RUFF)])
CRC	MAX(MIN(LONG, PTCH, RUFF), [AVG(LONG, PTCH, RUFF) – 0.85 STD(LONG, PTCH, RUFF)])

Table 34
Trigger values for the selection of flexible pavement treatments

#	TREATMENT	TREATMENT	ALLIGATOR	RANDOM	PATCH	RUT	ROUGHNESS
1	bfTRG_MS_ASP_INT	Microsurfacing on Interstate	>=98	>=98	>=98	>=80 <90	>=85
2	bfTRG_TO_ASP_INT	Thin Overlay on Interstate (Cold Plane 2", put 2" back; 0-100 sq.yds. Patching)	>=90	>=85	>=90	<80	>=85 <90
3	bfTRG_MO_ASP_INT	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	bfTRG_SO_ASP_INT	Structural Overlay on Interstate (7" Overlay; 700 sq.yds. Patching)	<65		<65		
5	bfTRG_MS_ASP_ART	Microsurfacing on Arterial	>=95	>=95	>=95	>=65 <80	>=80
6	bfTRG_TO_ASP_ART	Thin Overlay on Arterial (Cold Plane 2", put 2" back; 0-100 sq.yd. Patching)	>=90	>=80 <95	>=80	<65	>=70 <80
7	bfTRG_MO_ASP_ART	Medium Overlay on Arterial (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-300 sq.yds Patching)	>=50 <90	<80	>=60 <80		<70
8	bfTRG_SO_ASP_ART	Structural Overlay on Arterial (5.5" Overlay; 700 sq.yds. Patching)	<50		<60		
9	bfTRG_PST_ASP_COL	Polymer Surface Treatment on Collector	>= 85 <95	>=80 <95	>=85	>=65	>=80
10	bfTRG_MS_ASP_COL	Microsurfacing on Collector	>=95	>=95	>=95	>=65 <80	>=80
11	bfTRG_TO_ASP_COL	Thin Overlay on Collector (2" Overlay; 0-100 sq.yd. Patching)	N/A	N/A	N/A	N/A	N/A
12	bfTRG_MO_ASP_COL	Medium Overlay on Collector (Cold Plane 2", put 3.5" back or just 3.5" overlay, 100-500 sq.yds Patching)	>=60 <85	<80	>=65 <85	<65	>=60 <80
13	bfTRG_IPS	In Place Stabilization on Collector (In-Place Stabilization & 3" A.C.)	<60		<65		<60

Table 35
Trigger values for the selection of composite pavement treatments

#	TREATMENT	TREATMENT	ALLIGATOR	RANDOM	PATCH	RUT	ROUGHNESS	NO_LANES
1	bfTRG_MS_COM_INT	Microsurfacing on Interstate	>=98	>=95	>=98	>=80 <90	>=90	
2	bfTRG_TO_COM_INT	Thin Overlay on Interstate (Cold Plane 2", put 2" back; 0-100 sq.yds. Patching)	>=90	>=90	>=90	<80	>=85 <90	
3	bfTRG_MO_COM_INT	Medium Overlay on Interstate (Cold Plane 2", put 3.5" back & 1.5" on shoulders; 100-500 sq.yds Patching)	>=65 <90	>=65 <90	>=65 <90		<85	
4	bfTRG_SO_COM_INT	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	<65			
5	bfTRG_MS_COM_ART	Microsurfacing on Arterial	>=95	>=95	>=95	>=65 <80	>=80	
6	bfTRG_TO_COM_ART_CURB	Thin Overlay on Arterial (Curb & Gutter) (Cold Plane to slab, 300 sq.yds. Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	>=65 <90	>=65 <90	>=65 <90	<65	<80	
7	bfTRG_TO_COM_ART_NC	Thin Overlay on Arterial (Non-Curb & Gutter) (Cold Plane 2", put 2" back, 100 sq.yds. Patching, 30 tons Joint Repair)	>=90	>=80 <95	>=80	<65	>=70 <80	
8	bfTRG_MO_COM_ART_NC	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 <90	>=50 <80	>=60 <80		<70	
9	bfTRG_SO_COM_ART_CURB	Structural Overlay on Arterial (Curb & Gutter) (Cold Plane to slab, 1000 sq.yds. Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	<65	<65	<65			
10	bfTRG_SO_COM_ART_NC	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	<50	<60			<=3

Table 35
Trigger values for the selection of composite pavement treatments (continued)

#	TREATMENT	TREATMENT	ALLIGATOR	RANDOM	PATCH	RUT	ROUGHNESS	NO_LANES
11	bfTRG_RUBL_COM_ART_NC	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	<50	<60			>=4
12	bfTRG_MS_COM_COL	Microsurfacing on Collector	>=95	>=95	>=98	>=65 <80	>=80	
13	bfTRG_TO_COM_COL_CURB	Thin Overlay on Collector (Curb & Gutter) (Cold Plane to slab, 300 sq.yds. Concrete Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	>=65 <90	>=65 <90	>=65 <90	<65	<80	
14	bfTRG_TO_COM_COL_NC	Thin Overlay on Collector (Non-Curb & Gutter) (Cold Plane 2", put 2" back, 100 sq.yds. Patching, 30 tons Joint Repair)	>=80	>=80 <95	>=80	<65	>=65 <80	
15	bfTRG_MO_COM_COL_NC	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 <90	>=50 <80	>=60 <80		<65	
16	bfTRG_SO_COM_COL_CURB	Structural Overlay on Collector (Curb & Gutter) (Cold Plane to slab, 1000 sq.yds. Concrete Patching, Clean & Reseal Joints, 2" Saw & Seal Overlay)	<65	<65	<65			
17	bfTRG_SO_COL_NC	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	<50	<60			<=3
18	bfTRG_RUBL_COM_COL_NC	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)	<50	<50	<60			>=4

Table 36
Trigger values for the selection of jointed pavement treatments

#	TREATMENT	TREATMENT	TRANS	LONG	PATCH	FAULTING	ROUGHNESS	NO_LANES
1	bfTRG_SJC_JCP_INT	Seal Joints and Cracks on Interstate (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	>=80 <98	>=95 <98	>=90	<=0.2	>=85	
2	bfTRG_MNR_JCP_INT	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	bfTRG_MJR_JCP_INT_CURB	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	bfTRG_MJR_JCP_INT_NO_CURB	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	bfTRG_RUBL_JCP_INT_NC	Rubblize and Overlay on Interstate (Non-curb & Gutter) (Rubblize + 7" Overlay)	<65	<65	<65		<70	
6	bfTRG_CREC_JCP_INT	Reconstruct on Interstate(Curb & Gutter)	<40	<50	<50		<60	
7	bfTRG_SJC_JCP_ART_CURB	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	bfTRG_SJC_JCP_ART_NC	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	bfTRG_MNR_JCP_ART_CURB	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	bfTRG_MNR_JCP_ART_NC	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	bfTRG_MJR_JCP_ART_CURB	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	

Table 36
Trigger values for the selection of jointed pavement treatments (continued)

#	TREATMENT	TREATMENT	TRANS	LONG	PATCH	FAULTING	ROUGHNESS	NO_LANES
12	bfTRG_MJR_JCP_ART_NC_3LN	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	bfTRG_MJR_JCP_ART_NC_4LN	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	bfTRG_RUBL_JCP_ART_NC	Rubblize and Overlay on Arterial (Non-curb & Gutter) (Rubblize + 5" Overlay)	<50	<50	<60			>=4
15	bfTRG_SJC_JCP_COL_CURB	Seal Joints and Cracks on Collector (Curb & Gutter) (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	>=80 <98	>=95 <98	>=90	<=0.2	>=85	
16	bfTRG_SJC_JCP_COL_NC	Seal Joints and Cracks on Collector (Non-curb & Gutter) (Crack Sealing Plus Clean & Reseal Joints, Minor Patching)	>=80 <98	>=95 <98	>=90	<=0.2	>=85	
17	bfTRG_MNR_JCP_COL_CURB	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 <80	>=60 <95	>=65 <90		>=60 <85	
18	bfTRG_MNR_JCP_COL_NC	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.))	>=60 <80	>=60 <95	>=65 <90		>=60 <85	
19	bfTRG_MJR_JCP_COL_CURB	Major Rehab on Collector (Curb & Gutter) (Minor Rehab. Plus up to 800 sq.yds. Full Depth Patching plus 2" Saw & Seal Overlay)	<60	<60	<65	>=.5	<60	
20	bfTRG_MJR_JCP_COL_NC_3LN	Major Rehab on Collector (Non-curb & Gutter) (Minor Rehab. Plus up to 800 sq.yds. Full Depth Patching plus 3.5" Saw & Seal Overlay)	<60	<60	<65	>=.5	<60	<=3
21	bfTRG_MJR_JCP_COL_NC_4LN	Major Rehab on Collector (Non-curb & Gutter) (Minor Rehab. Plus up to 800 sq.yds. Full Depth Patching plus 3.5" Saw & Seal Overlay)	>=50 <60	>=50 <60	>=55 <65	>=.5	<60	>=4
22	bfTRG_RUBL_JCP_COL_NC	Rubblize and Overlay on Collector (Non-curb & Gutter) (Rubblize + 5" Overlay)	<50	<50	<55			>=4

Table 37
Trigger values for the selection of CRC pavement treatments

#	TREATMENT	TREATMENT	LONG	PATCH	ROUGHNESS
1	bfTRG_MNR_CRCP_INT	Minor Rehab on Interstate (Not Greater Than: 200 sq.yds. of Full Depth Patching & 4” A.C. Overlay)	>=65 <85	>=70 <85	<76
2	bfTRG_MJR_CRCP_INT	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	bfTRG_CREC_CRCP_INT	Reconstruction or Unbonded Concrete Overlay on Interstate	<50	<50	
4	bfTRG_MNR_CRCP_OTHER	Minor Rehab on Other (Not Greater Than: 200 sq.yds. of Full Depth Patching & 4” A.C. Overlay)	>=65 <85	>=70 <85	<75
5	bfTRG_MJR_CRCP_OTHER	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	bfTRG_CREC_CRCP_OTHER	Reconstruction or Unbonded Concrete Overlay on Other	<50	<50	