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16. Abstract

The main objective of the 1727 project was to "evaluate and recommend improvements to pavement performance prediction models" for the Texas Pavement Management Information System (PMIS). The secondary objective was to strive toward more integration between network and project management levels such that the models used at each level do not contradict each other and result in a loss of confidence by users. The project evaluated models for portland cement concrete and asphalt concrete pavements and developed recommendations. The models for portland cement concrete are described and discussed in Report 1727-1. The models for asphalt pavements are described in that report, but the full evaluation report and recommendations are included in this report. The most important variables for various models were identified and reported in Report 1727-1. This report then develops the recommendations for modifications to the Texas Department of Transportation (TxDOT) PMIS to allow the network- and project-level models to be better integrated. This integration includes modifications to the PMIS software that would store the sigmoidal project parameters for each pavement section. This storage would allow the projection models to use the best available projection parameters, whether they came from a network-level model or a project-level model after detailed project level analysis. An approach to implementation is included.

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INTEGRATION OF NETWORK- AND PROJECT-LEVEL PERFORMANCE MODELS FOR TxDOT PMIS

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CHAPTER 1: INTRODUCTION

GENERAL

The Texas Department of Transportation (TxDOT) maintains over 184,000 lane-miles of rigid and flexible pavement (1). The total funding needs for pavement maintenance and rehabilitation (M&R) activity in the state of Texas for the 1996 financial year was approximately 1.74 billion dollars (1). Adequate justification is required to justify such large expenditures of public funds. Pavement management provides a method to substantiate the funds needed for pavement M&R. A pavement management system (PMS) is a set of decision support tools that assist pavement managers in planning, programming, designing, constructing, retrofitting, and abandoning of pavement sections (2). The objective of pavement management is to provide the most effective and economic facility to the users (2).

A pavement is a complicated structure because of its variability. Performance of pavements depends on hundreds of factors. After construction, the condition of a pavement gradually deteriorates with the development of different types of distress due to traffic and environmental factors. If not adequately maintained, the pavement condition becomes unacceptable, requiring heavy rehabilitation or reconstruction to return it to a usable condition. Two different types of pavement structures can have the same condition at a particular time, but their rates of deterioration may significantly differ. Stronger pavements last longer, but they require higher initial construction costs. Generally a minimum condition is used to trigger rehabilitation. However, the cost of rehabilitation decreases (with lighter treatment) as the time to rehabilitation decreases up to some point in time or condition level. The most cost-effective pavement is that which requires the least life-cycle cost. Life-cycle cost is the total cost of new construction and M&R during the entire life of a pavement adjusted for the time value of money.

Network- and Project-Level PMS

Pavements in a jurisdiction generally have different condition states, requiring different amounts of funds for rehabilitation. Therefore, three questions are generally asked in pavement M&R activity: 1) which section? 2) what treatment? and 3) when? (2). Since it is not feasible to determine the most effective treatment and the most appropriate time for the most appropriate set of sections through detailed design and cost optimization for every segment in the entire network, the earlier questions are commonly answered at two levels: 1) network level and 2) project level. In network level, the entire network is analyzed to identify the appropriate set of pavement sections with tentative broad treatment types for each planning year (2, 3). In project level, only the selected sections are analyzed to determine the actual treatment types (material and thickness) for each section (2, 3). It is generally the high cost of detailed data collection, data maintenance, computer storage, and run-time (for actual pavement design of all the sections) that prohibits a complete analysis of every segment in the network from being performed in one level (4). Moreover, pavement managers need to compete with other infrastructure and public service authorities for funds. Usually transportation agencies suffer from fund constraints and, in the absence of adequate funds, detailed engineering for the entire network is superfluous. As a result, most agencies normally manage pavements at a minimum of two levels.

The purpose of network-level management is to determine the needs of the network, to select pavement sections that are the best candidates for treatment for a given amount of money, and to determine the impact of different funding scenarios (2, 3). Thus network level is meant basically for the budget process. Project-level management, on the other hand, includes actual engineering design, construction, etc. The purpose of project-level PMS analysis is to determine the most cost-effective treatments for the selected pavement sections within available funding, materials, and other constraints (2, 3).

In network-level analysis, pavement sections are selected based on criteria, such as the worst section first, the least cost first, the highest benefit-cost ratio first, and others. The cost of treatment and the benefit (as real monetary benefit or effectiveness) or improvement (of condition or remaining life) expected upon treatment are the two guiding parameters in the selection process. The treatment costs, however, are usually estimated using broad unit cost categories, such as light rehabilitation, heavy rehabilitation, etc., corresponding to broad treatment categories commensurate with the existing condition of pavement sections (4).

BACKGROUND

Compatibility between Two Levels

It is essential that network- and project-level PMS be compatible. The cost assigned to the selected pavement sections at network level and the cost of the actual treatment (at project level) for the same performance should be approximately equal. For example, suppose a network-level PMS assigns a sum of $150,000 to a pavement section with an existing serviceability index (SI) of 2.5 for medium rehabilitation expecting that the pavement will be deteriorated back to a SI of 2.5 after 16 years. On the other hand, the project-level PMS computes an optimum overlay thickness of 3 inches of asphalt concrete (AC) commensurate with the same performance period of 16 years and terminal SI of 2.5. Now, if the cost of 3-inch AC is approximately $150,000 and the pavement actually performs as predicted, then the pavement management systems at network and project level could be considered compatible. Generally, incompatibility between network and project level arises from the use of different performance models that predict different condition measures and different input data. They generally also provide different levels of accuracy. Other elements, such as unit cost of treatment, database, etc., can also cause differences.

The complete implementation and success of a pavement management system lies with trust, adoption, and use of the system (4). Therefore, to achieve confidence of the pavement managers in the PMS, performance models must provide an acceptable level of accuracy. Requirements of pavement performance models are discussed in more detail in the first report (5).

The Problem

The Pavement Management Information System (PMIS) and the flexible pavement design software, FPS-19, used by the Texas Department of Transportation (TxDOT) for pavement management at network and project level, respectively, generally do not give the same solution when the same set of data is used.

As pointed out by the TxDOT project director in an expert panel meeting, the network- and project-level pavement management at the district level are not necessarily performed at two distinct stages. Many times, a single person in the district completes pavement analysis at all levels. Since the same engineers are performing the network- and project-level analysis, they expect to find similar results. He further added that a certain amount of integration in terms of data collection is taking place. As such, the pavement condition survey method in TxDOT is gradually migrating towards the automated technology, where rut and ride data are collected exactly in the same fashion for both the levels. Therefore, the feasibility of integration of the network-and project-level management needs to be studied. Since performance prediction models play a vital role in pavement management, integration of the performance models used at the two levels is the first step towards the final goal. This report is part of a study to find an appropriate solution. The following four options for integrating performance models at the two levels were considered:

- Do nothing.
- Change only network-level performance models.
- Change only project-level performance models.
- Change both network- and project-level performance models.

Integrating PMS Levels

A recent publication describing performance-related specifications (PRS) by the Federal Highway Administration opens by stating: "Providing roadways of the highest possible quality (6). This has always been the commitment of the highway community to the travelling public." PRS represents a new and much stronger link between design and construction but in order to attain this goal in an even more global sense, agencies need to design, construct, *and* plan for future maintenance of their highways with "highest possible quality" as their primary objective.

By "quality" we can infer the time history of condition or performance. Including performance of roadways in all three of these tasks implies predicting future serviceability with and without possible maintenance, rehabilitation, or reconstruction actions performed during the analysis period. In addition to this, if predictions are made during this process and a record kept such that these predictions can be compared with *actual* performance, these predictions should be able to be compared and continually improved over time.

By explicitly including performance in the process, this allows us to formally and quantitatively tie together the three major activities of planning, design, and construction such that all three can be part of a seamless system as illustrated in figure 1.1.

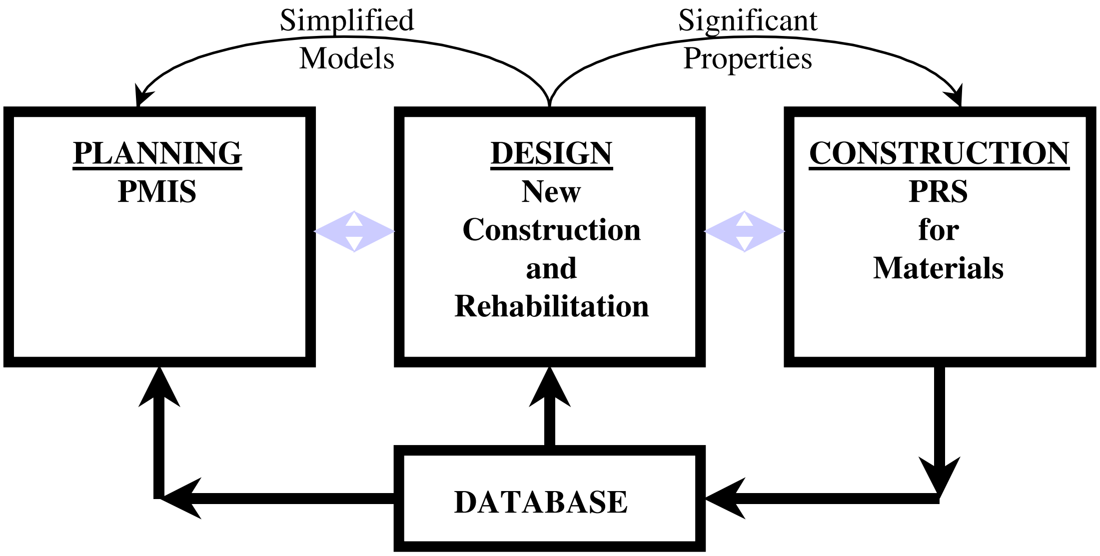


Figure 1.1 The Link between Planning, Design, and Construction

In the figure, simplified models and significant properties, both for the prediction of performance, are researched and developed primarily for the design stage and then passed out for use in the planning and construction phases.

This extension of design to planning and construction is again reinforced from definitions of pavement management in general. In their book, “Modern Pavement Management,” Haas and Hudson state in the introduction that “It has only been recently that ‘design’ itself has been elevated from the concept of specifying an initial structural section to that of a ‘strategy’ where the strategy is an optimized design involving not only the best initial construction and structural section but also the best combination of materials, construction and structural section but also the best combination of materials, construction policies, maintenance policies, and overlays” (2). To paraphrase this statement, pavement management involves choosing the best life-cycle strategy of maintenance for a road section (at project level) or sections (at network level).

Using this definition it can be seen that pavement management already implies strong links between initial design, maintenance, and rehabilitation for the entire life cycle, and implementation of this plan (construction both of the initial design and the planned maintenance and rehabilitation). In order for the links to result in a seamless pavement management system, it can be seen from the figure that a single (at least in a 'virtual' sense) database is vital. Another necessity (which has been a major limiting factor in certain statewide pavement management systems such as Arizona's network optimization system (NOS)) is that the individual identity of road sections is preserved since no detailed planning can take place without this. The final necessity is that the objectives at each stage are ultimately the same: "Providing roadways of the highest possible quality…..to the travelling public."

With the introduction of the 'individual model' concept in this and the previous report, and with a strong recommendation for seamless links between databases, it is expected that these necessities for a sound foundation database, preservation of individual road section identities, and common objectives will be met.

REPORT ORGANIZATION

The objectives of this report are therefore to:

- Discuss how the implementation of the proposed concept of 'individual models' fits in to the general scope of pavement management and make strong recommendations for necessary supporting structure such as the development of a strong foundation database, and the adoption of compatible objectives in planning, design and construction.
- Explain the concept of maintaining individual models for each section and its general ramifications for the Texas PMIS.
- Provide results of the detailed analysis of flexible pavement models used by TxDOT.

- Provide recommendations for changes to PMIS to allow the integration of network- and project-level performance projection parameters.

The report is organized as follows:

- Chapter 1 includes an introduction to the research problem and appropriate background information related to trying to integrate management levels in pavement management activities.
- Chapter 2 addresses the need and an approach for integrating network- and project-level performance projection models.
- Chapter 3 includes the results of a thorough evaluation of the flexible pavement models used by TxDOT.
- Chapter 4 includes recommended changes to the TxDOT PMIS to support efforts to integrate network- and project-level performance models.
- Chapter 5 includes a summary of findings and recommendations.

CHAPTER 2: NEED FOR NETWORK- AND PROJECT-LEVEL MODEL INTEGRATION

INTRODUCTION

Although pavement management first started as the application of systems engineering concepts to pavement design, most of the emphasis changed to project-level analysis and management to support funding decisions, allocation of funds, and selection of sections for repair. While this change in emphasis was occurring, the pavement design community continued using and improving its design procedures. In most agencies, including TxDOT, the models used at network and project level were not the same. The reasons are many and valid; however, there is a real need to at least develop a plan and method that would allow them to be merged. Many of these reasons are discussed in this chapter, with performance-based specifications being identified as one of the things that should be considered.

THE CONTINUOUS EVOLUTION OF ROADWAYS

In theory, a highway section should be monitored so that its performance is both known for some time over the past as well as predicted for some time into the future. In a long-term planning view, the prediction into the future may include the next couple of planned maintenance actions or may even include a whole life cycle. As future planned maintenance actions approach, these may require more detailed design and then they will be constructed and pass into history. Figure 2.1 illustrates this point.

At any one time, some planned maintenance actions may be on the horizon (both in front and behind). One action might be undergoing detailed design, and one may have been constructed in the not too distant past. For this reason, we need to consider the evolutionary path of the road section through each individual maintenance action.

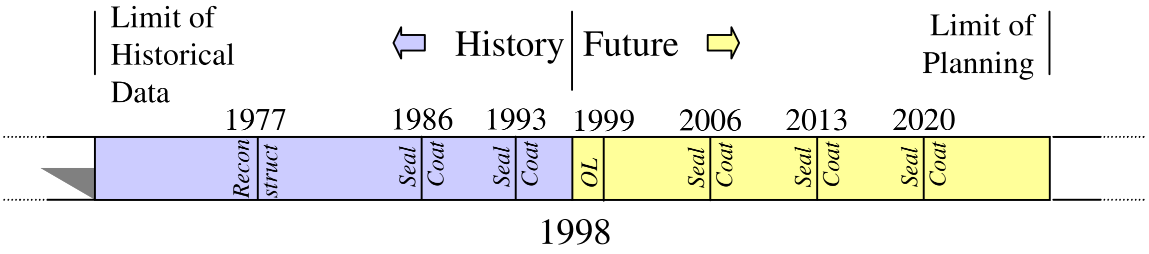


Figure 2.1 The Continuous Evolution of a Road Section

Although a road section will in fact only *follow* one path in the future, it is possible that it *could* evolve along a number of different paths depending on the decisions regarding both what maintenance actions to perform and when to perform them. Figure 2.2. illustrates this point.

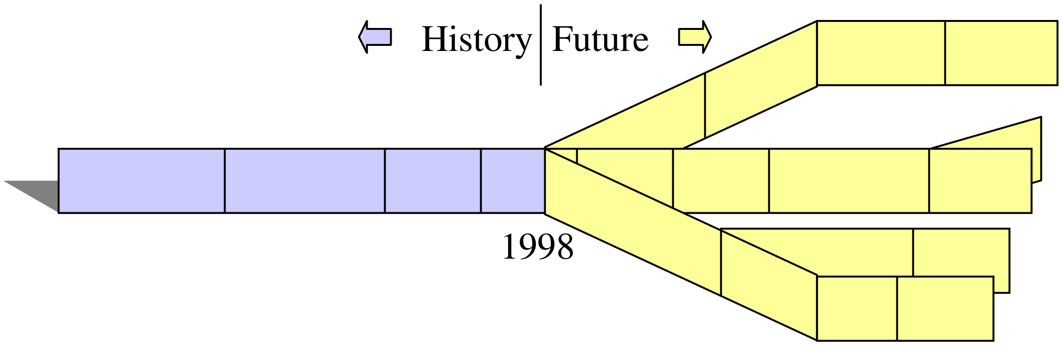


Figure 2.2 Possible Future Evolution Paths of a Roadway

For planning purposes we need to at least be able to assess different possible paths (if not every possible path) which in turn requires a prediction model. The accuracy of the analysis depends on this model, and the more customization we use, the more we can increase the accuracy for individual sections, made possible by more accurate data, etc.

PLANNING

Definition and Requirements

In order to plan effectively it is necessary to choose the best of the possible paths discussed above. The tool most widely accepted is the life-cycle cost analysis (LCCA).

By the assessing the life-cycle costs of a number of alternatives, the best alternative can be identified. In fact this assessment completely ignores performance as an objective and relegates it to a constraint (e.g., the PSI should not fall below 2.5). In order to perform an LCCA, it is still vital to know how the road will perform in the future in order to ensure it is kept within the chosen constraints. True optimum planning thus involves predicting performance, cost, user, delay etc. for every possible path in the future, and choosing the best course of action by finding some desired balance between the chosen objectives. In practice, unless full-scale optimization is implemented, only a small portion of the total number of possible paths is actually analyzed, but it is still necessary to be *able* to analyze any path.

The 'path' basically represents a particular combination of specific M&R actions at specific times. Thus, a *strategy* has been defined by this particular combination of M&R actions.

Planning Objectives

The first step in planning is choosing objectives by which to compare alternative strategies. Ultimately, the basic objective is to choose strategies that result in the "highest possible quality" for the travelling public within the imposed constraints.

Quality in this case can mean a number of things, but it was originally assumed to be related to ride quality. This led Carey and Irick to develop the well-known present serviceability index (PSI) in preparation for the American Association of State Highway Officials (AASHO) road test (6). It was no great surprise that slope variance (a measure of roughness) was the most significant variable for both rigid and flexible pavements in the PSI equations. Interestingly, the PSI was developed for design purposes. The obvious conclusion is that the ultimate objectives from the user's point of view are identical. Comfort may be added to such things as convenience (such that too much disruption of traffic caused by excessive maintenance is undesirable) and safety, but these all have to be balanced against the cost, or agency cost. If an agency is trying to spread its budget as widely as possible, it will try to establish minimum levels of acceptable performance. If a road drops below a particular level of serviceability, it is deemed 'failed.' In this way, a single objective, agency cost, can be minimized subject to a ‘failure’ constraint in terms of performance. Nonetheless, the performance still has to be predicted to know when the ‘failure’ threshold is crossed.

Unfortunately, in design and to a lesser extent in planning, in order to predict performance of a roadway it is necessary to know the *mode* by which the serviceability of the road is deteriorating. Numerous distress measurements are needed on a continuous basis. It is very important to note, however, that these are the means to the end of predicting user serviceability and subsequently performance.

Although ‘performance’ can be broken down into comfort, convenience, safety, etc., the fundamental trade-off can be summarized as a balance between user-oriented performance and agency cost.

Multi–Objective Optimization

In the past, a number of indices combining the two major objectives of performance and cost have been developed. These include benefit-cost ratio (B/C), cost effectiveness (CE), and many more. The goal was to consider user-oriented performance in the optimization process rather than simply prescribing a minimum performance level and minimizing the agency cost. In fact, whether all but one of the original objectives are reduced to constraints, the different objectives are combined into a single final objective, or the objectives are converted to a single utility value for planning purposes, maximizing performance and minimizing cost are fundamental goals in road management.

Performance prediction (in whatever form desired) is therefore vital, as is cost prediction, for any strategy as these ultimately represent multiple objectives even when one or the other is portrayed as a constraint.

LINK BETWEEN DESIGN AND CONSTRUCTION

Performance-Related Specifications

The importance of performance as a management objective can be seen in the recent move by FHWA and state agencies to develop and adopt performance-related specifications. In general PRS are improved quality assurance specifications (7). The major distinguishing feature is that ‘rationally derived performance-related price adjustments’ are used to link the quality of the construction to the predicted performance of the road (7). The key here is that contractors’ payments are actually being adjusted based on performance predictions. This payment requires a very high level of dependence on performance prediction.

The general idea behind the use of PRS is that the client agency can calculate the future cost of attaining the designed performance based on the actual construction and compare it to the cost if the road were built exactly according to the design. If it is predicted that the maintenance costs will be higher due to poor construction or lower due to higher than expected construction quality, the payment to the contractor can be adjusted accordingly. This calculation requires models that predict values for the two previously identified objectives: performance and cost. Figure 2.3 illustrates this idea, which comes from FHWA publication FHWA-SA-97-098 (7).

It can be seen that the performance models illustrated in figure 2.3 are only supposed to predict “distress occurrence and extent.” By our previous discussion we identify performance with user-oriented serviceability and thus comfort/roughness and perhaps delay and safety. Nonetheless, as noted before, while prediction of roughness is desirable, the prediction of “distress occurrence and extent” is a better method to predict when the agency should intervene in the pavement life to preserve the agency’s investment in the pavement structure and to prevent the serviceability from becoming unacceptable.

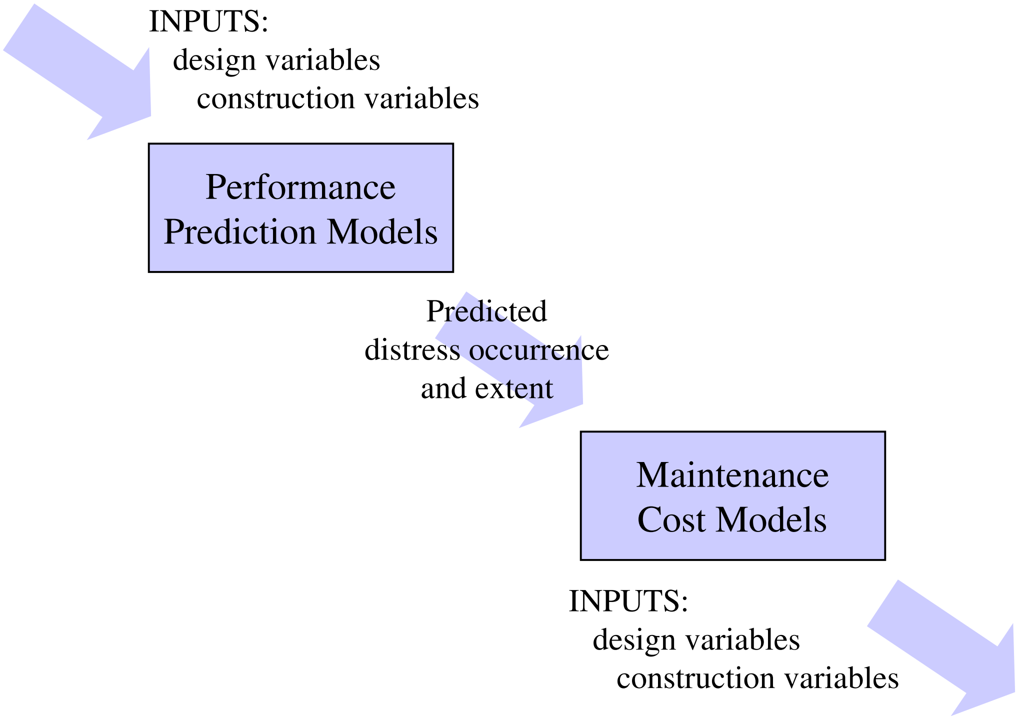


Figure 2.3 Use of Models in PRS (7)

Development of Performance Models in General

The prediction models are the cornerstone of both PRS (the link between design and construction) and planning. In the past the mechanisms of pavements' responses to load, the progression to deterioration, and their interconnectivity have not been well enough understood to convincingly tie measured levels of significant variables to future performance. This dependence is slowly changing, with the new emphasis being put on 'mechanistic-empirical' models, especially in such major undertakings as the upcoming American Association of State Highway and Transportation Officials (AASHTO) 2002 design guide.

In the past numerous models have been developed for different aspects of design, construction, and planning. One major limitation has been the amount of data available for use as input to the models – the data available for network-level planning has generally been sparse and lacking in detail. Now, however, with a better mechanistic knowledge of what constitutes the significant variables, data collection can be concentrated around the most significant items and this, together with many vastly improved collection techniques, may allow the same mechanistic-empirical models to be used with varying levels of data accuracy for all phases of management. The current flow of information and development of models through research and calibration with collected data is illustrated in figure 2.4. The data collection is split into condition data collection on existing roads and data collection during construction. This data has three main destinations: either it is collected as part of a unique case study, or it might include a number of variables under investigation for a research database but still not include data from the whole network, or it can be planning and reporting data, which should contain the major significant variables for the entire network. As a result of research into the mechanisms and calibration with the data, models are developed for different purposes ranging from design and analysis to the calculation of pay factors in PRS.

If basic prediction models of design become more strongly linked to construction through PRS, the entire system could be considered “performance-related management.” Firstly, however, it is necessary to address the problem of a central database and then to show how the specific requirements of planning affect the performance models so that these now are actually stored individually and therefore become part of the network database.

Supporting Data

If predicting performance is the link between design and construction, it is vital to support this prediction with data. The entire connection rests on the fact that performance predicted for design should at least be similar to that used for payment factors in PRS. In order for this performance prediction to be the same, both the models and the data need to be the same.

While it is proposed that the common models are the ‘individual models’ explained in this report, in fact, as indicated earlier, these models, *because* they are ‘individual,’ ultimately *include* the data since they are really performance curves of a particular form with the entire set of underlying data and sub-models summarized in the particular values of the shape coefficients. It is therefore not the intention that the detailed

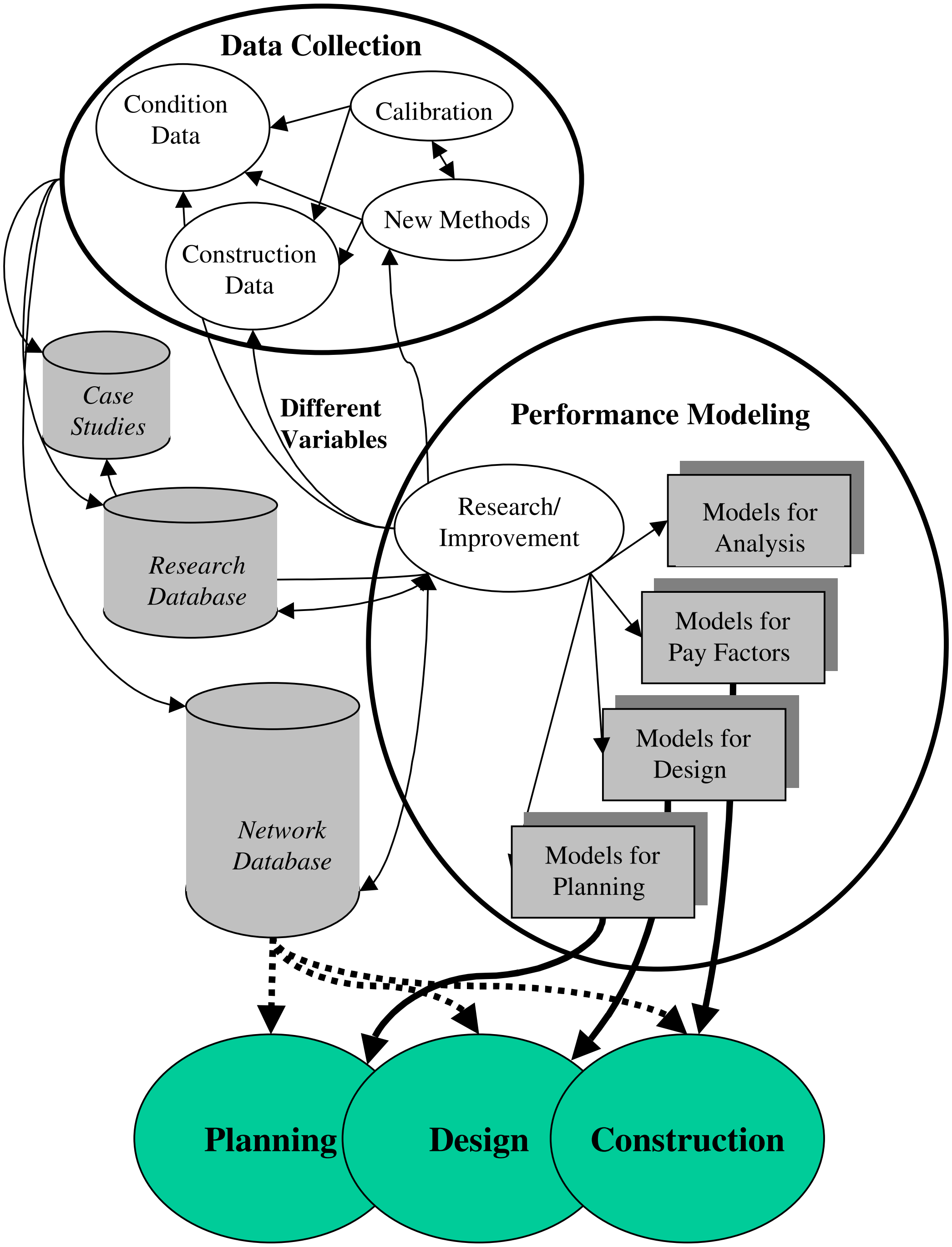


Figure 2.4 Current Flow of Data

data necessarily be the same for any two similar sections but only that the final individual performance curves (summarizing both models and data) are the same on any *particular* section for both design and construction. The same data and models would then be used for the performance prediction in both design and construction phases on that section. In this case it is therefore the individual models that are stored for every network section that are the basis of the single ‘central’ data base since whatever the origin of these models, they provide the data that is necessary for planning, that will be updated at design and that will be used for PRS price adjustment factors in construction.

LINKING PLANNING TO DESIGN AND CONSTRUCTION

Common Mechanism – Common Objectives

We have previously identified maximizing performance as the primary objective in planning, along with minimizing the cost. We have also shown that both design and construction have identical objectives to planning because all three make up the major components of pavement management.

It is, therefore, now apparent that the management of pavements is primarily driven by a set of common objectives loosely termed performance and cost objectives. This is the kernel of pavement management. These performance objectives are subject, in turn, to deterioration by a common mechanism. Discovering this mechanism of performance deterioration and its conversion to models is the subject of continuous research. Models, in turn, allow us to predict performance over time and hence balance this deterioration against the other major objective: minimizing the cost.

Generally Applicable Mechanistic Models

The first models developed, while sound in many ways, often relied on more surrogate measurements, and often these models were tailored to a specific activity such as network-level models for planning and more analytical models for design. The kernel of pavement management objectives surrounded by the mechanism for performance deterioration and the research interface between this actual mechanism and the development of rough, surrogate models for separate activities are shown in figure 2.5.

It can be seen that there is no direct practical connection between the activities in this picture of management since there is no overlap between the models. While the activities are connected in theory by common objectives and a common deterioration mechanism, only a thin layer of mechanistic or mechanistic-empirical models surrounded the research interface and this may not extend all the way around.

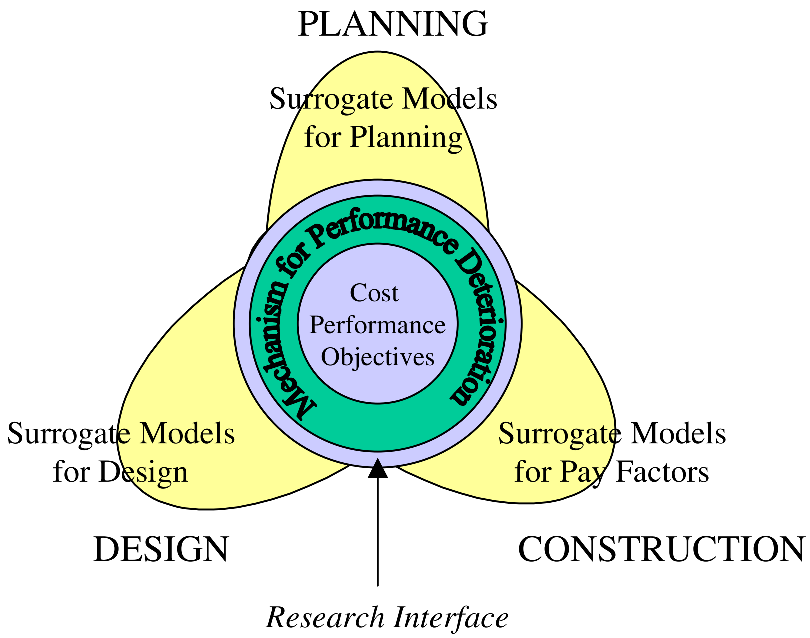


Figure 2.5 Previously Largely Unconnected Models Were Used for Planning, Design, and Construction

With the continuing development of these mechanistic-empirical models, this layer has effectively slowly increased in thickness. It can now provide a useful, practical connection between the different activities of pavement management. In fact where once pavement management was almost wholly concerned with reporting and planning, it can now usefully connect and indeed become the umbrella under which all three activities of planning, design, and construction take place. The increased thickness of the mechanistic-empirical models layer that makes this possible is shown in figure 2.6.

Incorporating Life-Cycle Prediction Models for Planning

The main purpose of models used for design and construction has been to predict performance deterioration – what the future performance of the pavement will be as a result of selected maintenance or rehabilitation action. During design we might have considered the future performance for a number of alternative M&R actions, but we still were interested only in predicting what would happen if we did the action now. In order to plan effectively we need to broaden the prediction scope one level further. As shown in figure 2.2, in order to plan effectively we need to predict performance after any maintenance action is done at any time in the future. In order to properly link planning into the picture, we need to develop models that can evaluate performance for any alternative M&R *strategy* made up of any set of M&R actions performed over an analysis period or life cycle.

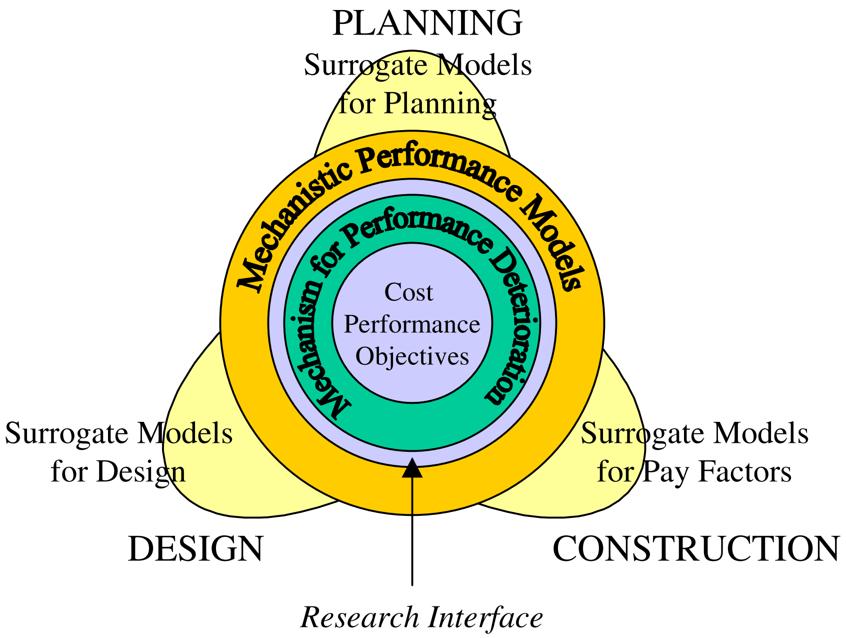


Figure 2.6 Mechanistic-Empirical Models Providing a Closer Link between Planning, Design, and Construction Performance Prediction

The Development of Individual Models

General mechanistic-empirical models that can predict performance for a wide variety of input variables are becoming more common. An illustration of such a model is presented in figure 2.7.

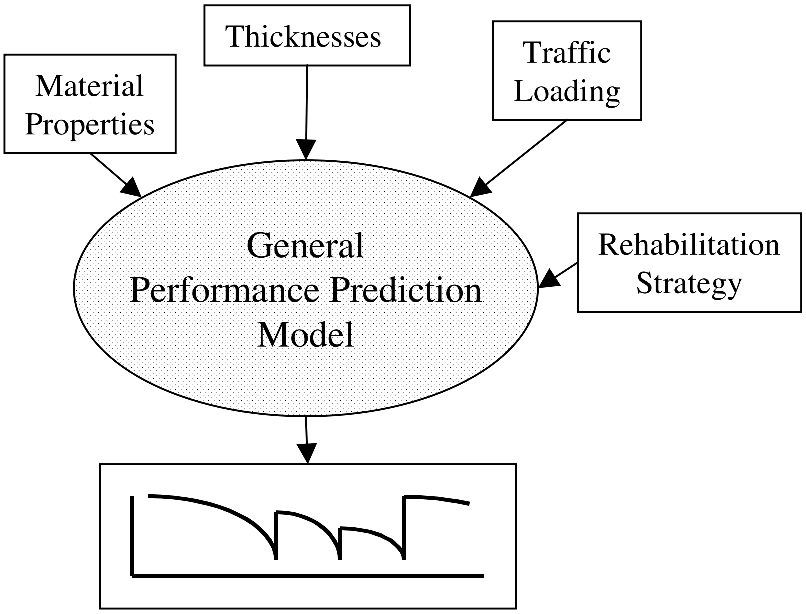


Figure 2.7 General Model for Prediction of Life-Cycle Performance

Unfortunately, limitations to generalization still exist so the aim of the individual model concept presented in this report is to allow flexibility in the development of each model for each section so that it incorporates the specific nature of a particular section, allows for the possibility that available data may be different and therefore require slightly different models, and yet still allows prediction for any given M&R strategy. This approach allows the basic individual model to be developed using the best available data, and it allows the most sophisticated mechanistic-empirical models to be used or a model that relies on expert opinion from the field. The proposed individual models are therefore a summarization of sub-models and data since they give the prediction of performance (in terms of distress and ride prediction) for the current pavement into the future for any M&R strategy. This concept is shown in figure 2.8.

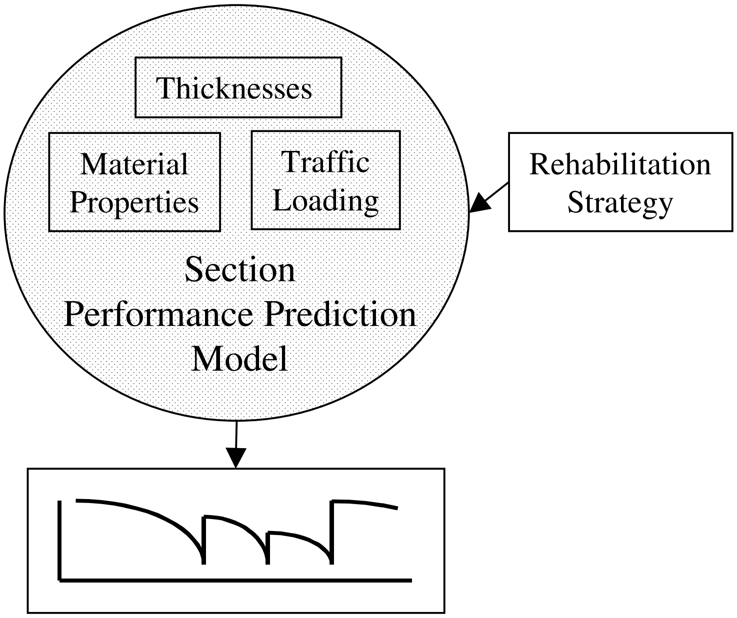


Figure 2.8 Individual Model for Prediction of Life-Cycle Performance

PERFORMANCE-RELATED MANAGEMENT

It is really unnecessary to coin yet another new phrase since pavement management already incorporates performance. In order to emphasize performance as the connection in the overall process, it may be useful to view the linking of planning, design, and construction through the use of individual performance prediction models as “performance-related management (PRM)” in the same way as the linking of only design and construction using performance has been termed performance-related specifications.

In order to fully comprehend what we might ultimately mean by PRM we need to look at the flow of information in such a system. Figure 2.4 shows the interaction of performance model development with the different sources of road data and how this data is combined with a number of different models for prediction of a number of activities. The illustration of a single network database is already idealistic as it implies that all construction conditions and the design data are going into the same database. If we assume that we are now more capable than ever before of providing a single set of common performance prediction models to link planning, design, and construction as illustrated in figure 2.6, then in theory this common set of models should only need a single data source.

While this single-model approach remains the ultimate goal, the path to this goal will be in a continuously changing dynamic system in which new data and new research will continually result in updates to the predicted performance and currently favored future M&R strategy for each road section. The concept described in this report, storing individual models and strategies so that the current best prediction of the future performance of any road section can be viewed at any time, represents a significant step toward creating a performance-related management system that can accommodate this dynamic process of trying to provide “roadways of the highest possible quality.”

CHAPTER 3: EVALUATION OF EXISTING PERFORMANCE EQUATIONS FOR FLEXIBLE PAVEMENTS USED IN TXDOT

EVALUATION OF FLEXIBLE PAVEMENT PERFORMANCE MODELS

The purpose of this part of the research work was to evaluate the existing flexible pavement performance prediction models used by TxDOT for network- and project-level pavement management. This project was performed to identify which performance models needed to be modified and which were working satisfactorily. This determination is a major step towards the integration of network- and project-level pavement management systems for flexible pavements in TxDOT.

INVESTIGATION

To initiate the process of integration of the performance models with the most important and fundamental characteristics of flexible pavements the project investigates pavement prediction models for the following three fundamental performance measures:

- serviceability/ride quality,
- fatigue cracking, and
- rutting.

From the family of flexible pavements, newly constructed pavements with untreated bases were given priority and investigated in this research as an initial step. Long-term pavement performance (LTPP) data from the strategic highway research project (SHRP) Texas sites were used to check the performance equations. In addition, sensitivity analysis of FPS-19 was performed along with a detailed study of the working of FPS-19.

Efforts were exercised to use metric units for all quantities in this report. However, since PMIS and FPS-19 use English units, it was not possible to provide metric units throughout.

DEVELOPMENT OF RESEARCH DATABASE

The PMIS performance models and FPS-19 require specific data to predict pavement performance and design pavements. Therefore, a specific database was required that would provide all information on selected Texas pavements to evaluate the performance models using the observed and the corresponding predicted performance. The PMIS database provides inventory, condition, and traffic data. However, since it does not contain historical data for construction and maintenance activities, the PMIS database could not be used in developing or calibrating performance equations such as a mechanistic-empirical equation requiring that data. The LTPP database was selected as the most complete source of Texas pavement data for evaluating performance equations. The LTPP database was developed to support pavement research (8). It includes inventory data, material properties, condition data, M&R data, deflection data, traffic data, and environmental data for evaluated pavement sections at various geographic locations. An important aspect of the LTPP database is that data quality controls (QC) are implemented to ensure accuracy of data. The LTPP program does not release any data if the data have not passed through proper QC checks.

Long-Term Pavement Performance Data

The strategic highway research program (SHRP) was a five-year, $150 million research program funded through a set-aside of state-apportioned federal highway aid funds. SHRP was authorized by Congress under the 1987 Highway Act. “SHRP was a strategic program because it concentrated on a short list of high payoff activities where even modest progress yielded savings which exceeded the research costs” (8). Asphalt technology, pavement performance, concrete and structures, and highway operations were the broad activities of the SHRP. The LTPP program under SHRP was scheduled for a 20-year period. In July 1992, LTPP became an FHWA-managed effort with responsibilities for the remaining 15 years shifted to the Pavement Performance Division of the FHWA Office of Research and Development (8). The objectives of the LTPP program include (8):

- Evaluate existing design methods.
- Develop improved design methodologies and strategies for the rehabilitation of existing pavements.
- Develop improved design equations for new and reconstructed pavements.
- Determine the effects of loading, environment, material properties and variability, construction quality, and maintenance level on pavement distress and performance.
- Determine the effects of specific design features on pavement performance.
- Establish a national long-term pavement database to support SHRP objectives and future needs.

The LTPP Information Management System (LTPP IMS) is the main database. Data is collected by the technical contractors using the Data Collection Guide for Long-Term Pavement Performance. The technical contractors also enter the data into the IMS and implement quality control procedures (6).

LTPP Experiments

There are two complementary experiments in the LTPP program: 1) the general pavement studies (GPS) and 2) the specific pavement studies (SPS).

The GPS experiments use existing pavement sections nominated by state and provincial Department of Transportation (DOT) officials to satisfy evaluation criteria. The actual sections were selected by SHRP and the FHWA's Pavement Performance Division. The sections included in GPS include pavements with materials and structural designs that reflect the standard engineering practices in the USA and Canada (8). The GPS sections include originally constructed pavements or pavements after the first overlay. Test sections are located in all states in the USA and all provinces in Canada. The GPS experiments include approximately 1,100 sections in North America (USA and Canada). A variety of data is collected for each pavement section including material properties, structural and surface characteristics, pavement loading, construction and maintenance activities, and climatic information.

The SPS experiments are designed to evaluate items which are not included in the GPS. The SPS experiments are intended to provide necessary data to investigate and quantify factors that are important in predicting pavement performance. An SPS project generally includes a series of pavement sections situated at a single location. These sections are chosen so that they vary in structure or M&R treatments with all other factors remaining unchanged at a site (8). The SPS program provides project-specific and comprehensive baseline data. Some pavement sections are used in both of the experiments. The SPS experiments frequently required constructing new pavements or applying specific treatments to existing pavements.

There are several experiments included in the general and the specific pavement studies. The definition of each experiment in the GPS and SPS programs is given respectively in tables 3.1 and 3.2.

Table 3.1 Definitions of the GPS Experiments

Experiment	Definition
GPS-1	Asphalt Concrete (AC) on Granular Base
GPS-2	AC on Bound Base
GPS-3	Jointed Plain Concrete
GPS-4	Jointed Reinforced Concrete
GPS-5	Continuously Reinforced Concrete
GPS-6A	Existing AC Overlay on AC Pavements
GPS-6B	New AC Overlay on AC Pavements
GPS-7A	Existing AC Overlay on Portland Cement Concrete (PCC) Pavements
GPS-7B	New AC Overlay on PCC Pavements
GPS-8	Unbound PCC Overlay on PCC Pavements

In addition to the GPS and SPS programs, the seasonal monitoring program (SMP) was designed to provide information on variations in temperature and moisture content

Table 3.2 Definitions of the SPS Experiments

Experiment	Definition
SPS-1	Strategic Study of Structural Factors for Flexible Pavements
SPS-2	Strategic Study of Structural Factors for Rigid Pavements
SPS-3	Preventive Maintenance Effectiveness of Flexible Pavements
SPS-4	Preventive Maintenance Effectiveness of Rigid Pavements
SPS-5	Rehabilitation of Asphalt Concrete Pavements
SPS-6	Rehabilitation of Jointed Portland Cement Concrete Pavements
SPS-7	Bonded Portland Cement Concrete Overlays on Concrete Pavements
SPS-8	Study of Environmental Effects in the Absence of Heavy Loads
SPS-9	Validation of SHRP Asphalt Specification and Mix Design

within a pavement structure along with the effects of those changes. There are 64 sites, including both GPS and SPS sites, selected from the core group for the SMP study (8). The sites are divided into two groups, and each group is extensively monitored in alternate years. Climatic data is collected continuously throughout that year at all SMP sites. This program also includes monitoring of pavement strength in each month in alternate years.

Structure of the LTPP IMS

The LTPP IMS is organized in two levels composed of four regional offices and a technical assistance contractor (TAC) supervising the central IMS. The regions are identified as North Atlantic, North Central, Southern, and Western. The responsibilities of the regional offices include (8):

- data collection performed directly by the regional offices or provided to them from state highway agencies (SHA) or other contractors,
- data entry into the IMS of data provided either on paper forms or electronically, and
- data quality control.

The TAC is responsible for (8):

- data collection, entry, and quality control of climatic data,
- quality assurance of all LTPP data, and
- providing data to the public.

Data Quality Control

Quality control is an ongoing process to ensure that the data is as accurate, complete, and consistent as possible. LTPP uses the following five types of quality checks, A through E (8):

- Group A - Random checks of data are done to ensure correct data transfer from the regions to the central location.
- Group B - Initial experiment assignments are verified based on inventory data. For the remaining data, a set of dependency checks is completed to ensure that essential section information has been stored in the LTPP IMS.
- Group C - A minimum data search is done for critical elements. For example, testing data on layer type must include a description of the material, its location in the structure, and a non-zero thickness.
- Group D - Expanded range checks are applied to certain fields to identify data element values that fall outside an expected range.
- Group E - Intramodular checks are designed to verify the consistency of data within a record or between records. For example, in testing the description of the asphalt tests, results should match the description of the corresponding layer in the table on pavement structure.

Each data record bears a letter (A through E) showing the last check that was successfully done. The checks are performed sequentially A to E, and the last successful check is attached to the record. However, a record with a “D” identifier does not necessarily imply that the check “E” was unsuccessful. It may happen that the check “E” was not performed (8).

DataPave 97

DataPave 97 is a database management computer program, especially developed for easy extraction and presentation of LTPP IMS data. DataPave is available on CD-ROM. It contains much of the LTPP IMS data and allows access to standard IMS data in a variety of output formats. The program has the following five modules (9):

- LTPP section selection module - This module allows the user to select a set of pavement sections for any GPS or SPS experiment type, individual sections, by state or by group of states, by climatic region, and by LTPP region. Filters are available for average daily truck traffic, average annual daily traffic (AADT), precipitation, and freeze days for conditional selection.
- Data exploration/extraction module - This module is used to view and extract available data for the selected sections. It uses three lists for a piece of data. The first list contains the broad data category (i.e., inventory, monitoring, testing). The second list contains the titles of the tables under each broad data category. The last list contains all the data items (fields) of the table, data units, and reference names. Data can be extracted in: 1) Microsoft Access® file, 2) Excel 5.0® file, or 3) text file formats.
- Map module - In this module, sections can be selected using the map. The user can zoom and pan the entire map of North America.
- Chart/trend module - This module provides trends of roughness in international roughness index (IRI), transverse cracking, longitudinal cracking, fatigue cracking, faulting, spalling, and punchouts for the selected modules (four at a time). It also shows the FWD deflections along the sections.
- Presentation module - This module provides comprehensive information on location, climate, pavement structure, and traffic.

Data Extraction and Modification

Pertinent data for the research work was extracted from LTPP IMS using DataPave 97. Titles of the tables provided in DataPave 97 do not always give a clear indication of the content. For that reason, each table had to be thoroughly searched to locate some of the data items. In general, IMS data was extracted to Excel 5.0 format files. FWD data was extracted to text data (space delimited format) for further use.

Selection of Pavement Sections

The LTPP database contains 40 pavement sections under the GPS-1 experiment from the state of Texas. Since the objective of the research was to evaluate performance models for the original pavement sections (without any rehabilitation), and completeness of these sections with respect to all required data items was not certain, it was necessary to examine each of these 40 sections. The following tables of LTPP IMS were examined:

- inventory of pavement layer (INV_LAYER),
- inventory of pavement age (INV_AGE),
- inventory of major improvement (INV_MAJOR_IMP),
- maintenance history (MNT_HISTORY),
- maintenance history of asphalt patch (MNT_ASPHALT_PATCH),
- maintenance history of asphalt seal (MNT_ASPHALT_SEAL), and
- traffic data (TRF_EST_ANL_TOT_GPS_LN).

Table 3.3 shows information on maintenance activities, major improvements, and availability/usefulness of traffic data for all Texas pavement sections included in GPS-1. Table MNT_HISTORY gives the maintenance history of 16 sections. Table INV_MAJOR_IMP lists 12 sections for major improvement. Out of these 12 sections, 11 sections are the same as that listed in MNT_HISTORY. Only a few sections are listed in the tables for specific maintenance activities (i.e., asphalt patch, seal); however, these sections are listed in either of the first two tables. Therefore, 17 out of 40 sections were improved with some types of asphalt courses above the original surfaces.

Table 3.3 Inventory and Maintenance History of All Sections in Texas GPS-1

Inventory															Maintenance									Traffic	Condition		
															INV_MAJOR_IMP			MNT_HISTORY									
SHRP_ID	CONSTRUCTION_NO	SHA_DISTRICT_NO	COUNTY	CONSTRUCTION_DATE	TRAFFIC_OPEN_DATE	SUBBASE LAYER	GRANULAR BASE LAYER	INTERLAYER	SEAL COAT	BINDER COURSE	SEAL COAT	ORIGINAL SURFACE LAYER	SEAL COAT	FRICTION COURSE	MAJOR_IMP_YEAR	MAJOR_IMP_TYPE	MAJOR_IMP_THICKNESS	MAJOR_IMP_YEAR	MAJOR_IMP_TYPE	MAJOR_IMP_THICKNESS	MNT_AC_SEAL_YEAR	MNT_AC-SEAL_THICKNESS	MNT_AC_PATCH_YEAR	AVAILABLE & USEFUL	NO. OF RUT DATA	NO. OF CRACKING DATA	NO. OF ROUGHNESS DATA
						in	in	in	in	in	in	in	in	in			in										
0001	1	14	453	01-Mar-89	01-Apr-89		16.5			1.5		1.0												No	1	3	4
1039	1	18	139	01-Jun-82	01-Jun-82	6.0	14.0			5.5		1.5												Yes	0	0	0
1047	1	4	65	01-Sep-70	01-Jul-71	6.0	12.0			9.0		1.0												Yes	0	3	4
1050	1	17	185	01-Jun-83	01-Jul-85	8.0	10.0	0.8				1.0												Yes	3	4	4
1056	1	4	357	01-Jun-69	01-Jun-70		14.0		0.5			1.5						88	31	0.5	02-Jul-88	0.4		Yes	0	0	0
1060	1	16	391	01-Mar-86	01-Mar-86	8.0	12.0			5.7		1.3												Yes	2	7	10
1061	1	4	421	01-Jun-84	01-Nov-85		18.0		0.5			1.5												Yes	0	0	0
1065	1	4	359	01-Dec-69	01-May-70		7.0			5.0		1.5	0.3					86	28	0.5	23-Aug-95	0.6		Yes	0	3	2
1068	1	1	277	01-Jun-85	01-Jun-87	8.0	6.0			7.0		3.0												Yes	1	6	10
1076	1	5	445	01-Nov-77	01-Nov-77		10.5			3.5		2.0						86	22	0.5				Yes	1	3	4
1077	1	25	191	01-Jan-82	01-Jan-82		10.0			4.5		1.3												Yes	1	7	10
1087	1	10	423	01-Dec-73	01-Dec-73		8.0			6.0		1.5	0.3					85	31	0.5				Yes	1	3	2
1092	1	15	325	01-Jan-81	01-Sep-83	14.0	5.0		0.5	1.3		0.8		0.8	88	21	0.8	88	21	0.8	28-Aug-91	0.4		Yes	2	4	4
1093	1	15	13	01-Apr-80	01-Jun-80	14.5	12.0		0.5			2.0	0.5		88	19	1.0							No	0	1	0
1094	1	15	29	01-Nov-74	01-Aug-76		8.0		0.5	1.0		0.8												Yes	3	5	4
1096	1	15	325	01-Jul-79	01-Apr-81	6.0	8.0		0.5	6.0		0.8												Yes	1	3	4
1111	1	5	303	01-Sep-72	01-Sep-72		7.5			5.0		1.5	0.4		80/85	31	0.2/0.2	80/85	31/31	.5/0.5				Yes	1	3	4
1113	1	10	401	01-Jan-86	01-Jan-86		12.0		0.5			1.0												Yes	1	1	2
1116	1	10	401	01-Jul-87	01-Jul-87		12.0		0.5			1.0												No	0	0	1
1119	1	10	73	01-May-75	01-May-75		7.0			4.0	0.5	1.5	0.5											No	1	1	0
1122	1	15	493	01-Feb-74	01-Feb-74	6.0	16.0	0.5		1.5		1.5	0.5		84	28	0.5	84	28	0.4				Yes	4	8	12

Table 3.3 Inventory and Maintenance History of All Sections in Texas GPS-1 (continued)

Inventory															Maintenance									Traffic	Condition		
															INV_MAJOR_IMP			MNT_HISTORY									
SHRP_ID	CONSTRUCTION_NO	SHA_DISTRICT_NO	COUNTY	CONSTRUCTION_DATE	TRAFFIC_OPEN_DATE	SUBBASE LAYER	GRANULAR BASE LAYER	INTERLAYER	SEAL COAT	BINDER COURSE	SEAL COAT	ORIGINAL SURFACE LAYER	SEAL COAT	FRICTION COURSE	MAJOR_IMP_YEAR	MAJOR_IMP_TYPE	MAJOR_IMP_THICKNESS	MAJOR_IMP_YEAR	MAJOR_IMP_TYPE	MAJOR_IMP_THICKNESS	MNT_AC_SEAL_YEAR	MNT_AC-SEAL_THICKNESS	MNT_AC_PATCH_YEAR	AVAILABLE & USEFUL	NO. OF RUT DATA	NO. OF CRACKING DATA	NO. OF ROUGHNESS DATA
						in	in	in	in	in	in	in	in	in			in										
1123	1	15	265	01-Jan-76	01-Jan-76		9.0	1.0		1.5		1.5	1.1		82	29	1.1	82/88	29/33	1.1/0.5				Yes	2	0	0
1130	1	15	187	01-Oct-71	01-Aug-72	6.0	18.0					1.5	0.8											Yes	2	2	2
1168	1	10	499	01-Sep-85	01-Sep-85		11.0		0.5			1.0												Yes	1	3	4
1169	1	10	401	01-Aug-72	01-Aug-72		12.0	0.5				1.5	0.5		85	28	0.5	85	28	0.5				Yes	3	4	4
1174	1	16	355	01-May-73	01-May-75	6.0	12.0		0.5	3.0		1.5												No	2	5	5
1178	1	17	51	01-Jul-88	01-Jul-88	6.0	10.0			6.0		2.0												Yes	2	4	3
1181	1	16	297	01-Feb-80	01-May-80	6.0	10.0		0.5	5.5		1.5	0.5		86	31	0.5	86	31	0.5				No	1	3	5
1183	1	5	169	01-Feb-75	01-Feb-75		7.5			5.0		1.5	0.4					81	31	0.5			90/9	Yes	3	5	3
3579	1	10	467	01-Nov-87	01-Nov-87	6.0	10.0		0.5			1.5												Yes	3	5	4
3609	1	25	125	01-Jun-74	01-Jun-74		7.0			2.5		1.5	0.5		85	31	0.5	85	31	0.5				Yes	0	1	2
3729	1	21	61	01-Jun-83	01-Jun-83	12.0	10.0			8.0		2.0												Yes	2	4	5
3739	1	21	261	01-May-82	01-May-82	8.0	10.0					2.5	0.3											Yes	3	4	7
3749	1	21	131	01-Mar-81	01-Mar-81	8.0	8.0		0.5			1.5	0.3		87	31	0.3	87	31	0.3			95	Yes	5	6	5
3769	1	24	141	01-Jun-76	01-Jun-76		8.5	0.5				1.5	0.5		86	31	0.5	86	31	0.5				Yes	2	4	4
3835	1	17	41	01-Oct-91	01-Oct-91	6.0	14.0			6.0		1.5												No	2	3	3
3855	1	13	149	01-Oct-79	01-Oct-79	16.0	6.0		0.5			1.0	0.5		86	31	0.5	86	31	0.5				Yes	1	3	4
3865	1	23	333	01-Jul-69	01-Jul-69	12.0	8.0		0.5			1.5	1.0		79/86	28	0.2/0.2	79/86	28/28	0.5/05				Yes	3	4	4
3875	1	4	421	01-Jun-84	01-Nov-85		18.0		0.5			1.5												Yes	0	1	1
9005	1	15	29	01-Jul-86	01-Sep-86		9.0		0.5			1.0												Yes	3	6	4

Notes: 1. All data are extracted from LTPP IMS. Highlighted sections are selected.

2. Major_IMP_TYP codes: 19 AC Overlay, 21 Mechanical Premix Patch, 28/29 Surface Treatment, Single/Double Layer, & 31 Aggregate Seal Coat

Traffic data is not available for three sections (0001, 1116, and 3835). For two sections (1174 and 1181), traffic data is available for some period before the listed dates of construction. For example, traffic data for the section 1174 is available from 1-Jan-70, whereas, the date of construction is 1-May-73. For another two sections (1093 and 1119), traffic data is not available for some period after the dates of opening to traffic. Therefore, these seven sections were removed from analysis. There are also three sections (1039, 1056, 1061) for which no condition data (roughness, cracking, and rutting) is available.

In this way, 16 sections were finally selected (highlighted in table 3.3) for inclusion in the research database. Appendix A presents summary data sheets containing extracted and modified data for these 16 sections. Names of the source tables, extraction, and modification needed for each data element of the summary data sheets are described as follows.

Location

District and county numbers for each section were extracted from the table INV_ID. These are important input to both PMIS and FPS-19. County numbers given in the LTPP come from the Federal Information Processing System (FIPS) code and are different than those used in PMIS and FPS-19. County and district numbers corresponding to the PMIS system were determined from reference 8 using county names corresponding to the LTPP county number given in the LTPP code list.

The following data items were extracted from the table INV_ID:

- latitude and longitude,
- elevation,
- route number, and
- functional class.

Longitude and latitude were extracted in terms of degree-minute-second and then converted to degree (with two places after decimal) for presentation in the summary data sheets. The Texas reference marker (TRM) location of the selected sections was provided by the Design Division, Pavement Section, TxDOT. TRMs are essential for retrieving data from PMIS database. Table 3.4 presents location data for the selected sections.

Climatic Data

Climatic data items, such as climatic zone, freezing index, precipitation, days above 90 °F, and years of climatic data were taken directly from the presentation module of DataPave 97. Table 3.5 presents selected climatic data for the selected sections.

Inventory Data

The LTPP database does not provide information on properties of subgrade in the inventory data category that would indicate the potential for swelling soils, specifically in the table INV_SUBGRADE. The names of relevant inventory data items included in the summary data sheets are given below along with their source tables (7):

- length of section from INV_ID,
- number of lanes in each direction and lane width - from INV_GENERAL,
- type and width of paved shoulder - from INV_SHOULDER,
- pavement type and sub-surface drainage - from INV_GENERAL,
- construction date and traffic open date - from INV_AGE,
- layer thickness and layer description - from INV_LAYER, TST_AC01_LAYER, TST_L05A, TST_L05B, and
- percent lime - from INV_STABIL.

All selected sections are 152.4 m (500 ft) long with asphalt concrete surfacing over granular base (LTPP pavement type 1). In these sections, lanes are 3.6 m (12 ft) wide, and there are one to two lanes in each direction. Most of the sections have paved shoulders, generally with asphalt concrete. The age of these sections varies between 10 to 27 years with an average of 15 years. Several tables in the LTPP database contain layer thickness data.

Table 3.4 Location Data

SHRP ID	DISTRICT			COUNTY			Highway Route Number	Ele-vation	Latitude			Longitude			Functional Class	Texas Reference Marker
	Name	Number		Name	Number											
		SHRP	PMIS		SHRP	PMIS										
								ft	deg	min	sec	deg	min	sec		
1047	Amarillo	4	4	Carson	65	33	IH0040	3301	35	12	34.9	101	10	48.6	1	106.0
1050	Bryan	17	17	Grimes	185	94	SH0105	378	30	21	12.5	95	55	18.7	6	658.0
1060	Corpus Christi	16	16	Refugio	391	196	US0077	78	28	30	35.3	97	3	29.8	2	600.1
1068	Paris	1	1	Lamar	277	139	SH0019	445	33	30	21.8	95	35	21.4	2	211.0
1077	Childress	25	25	Hall	191	97	US0287	1835	34	32	19.3	100	26	6.6	2	216.0
1094	San Antonio	15	15	Bexar	29	15	SH0016	1109	29	36	8.4	98	42	27.5	2	578.0
1096	San Antonio	15	15	Medina	325	163	US0090	774	29	21	22.1	98	50	6.7	2	550.0
1113	Tyler	10	10	Rusk	401	201	US0259	445	31	57	27.7	94	42	0.4	2	305.0
1130	San Antonio	15	15	Guadalupe	187	95	SH0123	519	29	33	36.5	97	56	39.7	6	487.5
1168	Tyler	10	10	Wood	499	250	FM0564	418	32	40	46.4	95	27	58.3	8	665.7
1178	Bryan	17	17	Burleson	51	26	SH0021	425	30	33	38.5	96	40	11.4	2	624.0
3579	Tyler	10	10	Van Zandt	467	234	SH0019	49	32	37	1.5	95	50	54.4	6	280.0
3729	Pharr	21	21	Cameron	61	31	US0083	38	26	5	11.6	97	35	5.5	2	800.0
3739	Pharr	21	21	Kenedy	261	66	US0077	36	26	59	1.9	97	47	43.7	2	730.0
3875	Amarillo	4	4	Sherman	421	211	US0287	3602	36	9	54.5	102	1	38.0	2	40.0
9005	San Antonio	15	15	Bexar	29	15	FM1560	910	29	31	0.5	98	43	13.8	8	494.0

Notes:

1. Texas reference markers are obtained from Design Division, Pavement Section, TxDOT.
2. District and county numbers used in TxDOT-PMIS are taken from reference 8.
3. Other data items are retrieved from LTPP IMS.
4. FUNCTIONAL CLASS codes are:
   1 Rural Principal Arterial - Interstate
   2 Rural Principal Arterial - Other
   6 Rural Minor Arterial
   8 Rural Minor Collector

Table 3.5 Climatic Data

SHRP ID	Climatic Region	Freezing Index	Precipitation	Days Above 90 °F	Years of Data
		F-days	inch		
1047	Wet Freeze	253.1	22.3	56.0	20.0
1050	Wet No Freeze	27.2	38.0	90.0	6.0
1060	Wet No Freeze	6.2	33.1	96.0	5.0
1068	Wet No Freeze	96.8	50.2	78.0	4.0
1077	Wet Freeze	181.9	22.8	85.0	9.0
1094	Wet No Freeze	16.1	32.0	92.0	15.0
1096	Wet No Freeze	12.0	25.8	113.0	10.0
1113	Wet No Freeze	38.4	50.3	72.0	5.0
1130	Wet No Freeze	14.4	35.3	103.0	19.0
1168	Wet No Freeze	72.8	47.8	69.0	6.0
1178	Wet No Freeze	54.0	33.4	99.0	2.0
3579	Wet No Freeze	79.8	43.4	72.0	4.0
3729	Wet No Freeze	3.9	26.5	113.0	8.0
3739	Wet No Freeze	5.8	23.9	117.0	9.0
3875	Dry Freeze	367.5	19.2	51.0	6.0
9005	Wet No Freeze	12.8	29.6	105.0	5.0

Note:

1. All data in this table are taken from the Presentation Module of DataPave 97.

Layer thicknesses given in INV_LAYER are as-planned values, which generally vary significantly from core test data. Layer thicknesses obtained from core-tests conducted at the two ends of each test section are found in the table TST_AC01_LAYER. This table contains only the information on asphalt layers. The presentation module of DataPave 97 furnishes a description and thickness of each layer that are similar to those available for the data item "representative thickness" in the table TST_L05B. Although there are some small differences among the average thicknesses computed from the thickness data given in tables TST_AC01_LAYER and TST_L05A and the thickness data given in table TST_L05B, the representative thicknesses were selected for use in this project. The representative thicknesses were developed by the regional contractors based primarily on core tests at the two ends of the sections, exercising technical judgment wherever necessary. If core test data at the two ends differ significantly, special tests including test pits, ground-penetrating radar testing, etc. are performed to arrive at the representative thickness.

Several of the selected sections have subgrades treated with 3-6 percent lime. Although these pavements are identified as type 1 (for granular base), there are a few sections with base layers also treated with a small percentage (about 1 percent) of lime. However, since the percentages of lime are very low, these base layers were not considered as treated layers. In all of these sections there is no sub-surface drainage. Extracted and modified inventory data for the selected sections are given in table 3.6. Layer 2 is the first layer above the subgrade, and all layers are numbered sequentially in increasing values above this layer.

Monitoring Data

Roughness: Table MON_PROFILE_MASTER of LTPP IMS, under the broad data category monitoring, contains international roughness index (IRI in m/km) along the left and right wheel paths as well as the average of the two IRI values. This table provides IRI data collected over the period 1990-95. Generally, several runs were carried out on a single day. However, the total number of days of roughness measurement differs considerably (1 to 10) from section to section. To determine the average roughness on a particular date, IRI values obtained in all the good runs were considered. For this project, IRI values given in m/km were converted to present serviceability indexes (PSI), which are equivalent to ride score (RS) used in the PMIS and serviceability index (SI) used in the FPS-19, employing the following equation developed and currently followed by the TxDOT:

$$PSI = 8.853270363 - 4.425873151 IRI^{-.0.35} \tag{3.1}$$

If $PSI<0$, Then $PSI=0$

If $PSI>4.7$, Then

If $IRI<0.5$, Then $PSI=5.0$, Else $PSI=4.7$

where,

PSI = present serviceability index (scale 0-5), and

IRI = international roughness index (m/km).

Table 3.6 Inventory Data

SHRP ID	Section Length	LANE		PAVED SHOULDER				Pave-ment Type	DATE		LAYER THICKNESS AND TYPE							Sub-Surface Drainage
		No.	Width	Inner		Outer			Construc-tion	Open to Traffic	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	
				Width	Type	Width	Type											
	ft		ft	ft		ft					inch	inch	inch	inch	inch	inch	inch	
1047	500	2		4	AC	10	AC	1	01-Sep-70	01-Jul-71	14.4-TS	15.3-GB	7.4-AC	0.8-AC	0.7-AC	0.1-AC	1.1-AC	None
1050	500	1	12			8	AC	1	01-Jun-83	01-Jul-85	6.5-TS	9.6-GB	0.8-AC	1.0-AC				None
1060	500	2	12	4	AC	10	AC	1	01-Mar-86	01-Mar-86	6.0-TS	12.3-GB	5.8-AC	1.7-AC				None
1068	500	2	12	4	AC	10	AC	1	01-Jun-85	01-Jun-87	8.0-TS	6.0-GB	7.8-AC	3.1-AC				None
1077	500	2	12	4	PCC	10	PCC	1	01-Jan-82	01-Jan-82	10.4-GB	3.7-AC	1.4-AC					None
1094	500	2	12	6	AC	10	AC	1	01-Nov-74	01-Aug-76	8.4-GB	1.2-AC	0.7-AC					None
1096	500	2	12	6	AC	12	AC	1	01-Jul-79	01-Apr-81	8.1-GB	5.0-AC	1.5-AC	0.6-AC				None
1113	500	2	12	4	AC	10	AC	1	01-Jan-86	01-Jan-86	11.5-GB	0.7-AC	0.8-AC					None
1130	500	2	12	2	AC	20	AC	1	01-Oct-71	01-Aug-72	8.0-TS	17.9-GB	2.3-AC	0.4-AC				None
1168	500	1	12			8	AC	1	01-Sep-85	01-Sep-85	10.4-GB	0.4-AC	0.8-AC					None
1178	500	2	12	4	AC	10	AC	1	01-Jul-88	01-Jul-88	4.5-TS	10.8-GB	6.4-AC	2.1-AC				None
3579	500	1	12			10	AC	1	01-Nov-87	01-Nov-87	9.2-TS	10.8-GB	0.6-AC	1.1-AC				None
3729	500	2	12	3	AC	10	AC	1	01-Jun-83	01-Jun-83	999-TS	10.5-GB	8.1-AC	1.9-AC				None
3739	500	2	12	4	AC	10	AC	1	01-May-82	01-May-82	7.4-TS	11.4-GB	1.5-AC	0.3-AC				None
3875	500	2	12	4	PCC	4	PCC	1	01-Jun-84	01-Nov-85	16.7-GB	0.6-AC	1.0-AC					None
9005	500	1	12			6	AC	1	01-Jul-86	01-Sep-86	9.4-GB	0.4-AC	1.1-AC					None

Notes:

1. All data in this table are extracted from LTPP IMS.
2. Layer thickness data is taken from table TST_L05B of LTPP IMS.
3. Number of lanes is for each direction.
4. Pavement Type codes are:

1	Asphalt Concrete over Granular Base

5. Layer Type codes are:

TS	Treated Soil
GB	Granular Base
AC	Asphalt Concrete

Since the conversion equation is non-linear, each IRI value was first converted to a PSI value, and then the average (of PSI) value was calculated. Table 3.7 presents extracted and modified roughness data for all the selected sections.

Fatigue Cracking: The LTPP database provides distress data surveyed manually as well as using a semi-automated film-based system (the proprietary PASCO USA system, PADIUS process). A study of the variability of LTPP manual and film-based distress data showed that the standard deviation and the coefficient of variation for fatigue cracking data collected using the manual method are lower than those using PADIUS process (9). Considering this variability, manually surveyed cracking data given in the table MON_DIS_AC_REV of the LTPP IMS under the broad data category monitoring was selected for this study.

Table MON_DIS_AC_REV provides distress data surveyed during the period 1989-96; however, data is not available for every year in this period. The number of observations in each year for each section varies from zero to four. The total number of observations for each section varies significantly (1 to 7) among the sections. The LTPP IMS provides alligator cracking data in terms of quantity (sq.m.) and severity (low, medium, and high). Since the PMIS models use percent wheel path as the unit of alligator cracking, the area of cracking was converted to percent wheel path considering the wheel path definition given in the LTPP distress survey manual (10). Figure 3.1 shows the dimensions of wheel paths.

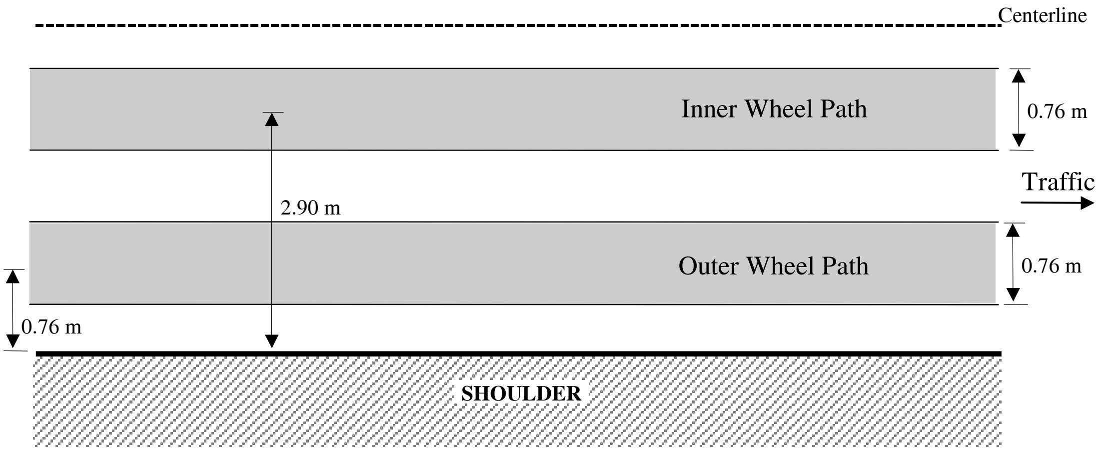


Figure 3.1 Location of Wheel Paths in Asphalt Concrete-Surfaced Pavements

Table 3.7 Roughness Data

SHRP ID	Profile Date	ROUGHNESS: IRI				ROUGHNESS: PSI				No. of Data
		Mean	Std. Dev	Max	Min	Mean	Std. Dev	Max	Min	
		m/km	m/km	m/km	m/km	m/km	m/km	m/km	m/km	
1047	29-Oct-90	2.080	0.0868	2.172	1.967	3.135	0.0837	3.245	3.047	10
1047	13-Nov-91	2.095	0.3059	2.438	1.755	3.133	0.2946	3.464	2.807	10
1047	07-May-93	2.165	0.1061	2.325	2.021	3.055	0.0995	3.192	2.907	10
1047	22-Nov-94	1.584	0.1260	1.737	1.438	3.658	0.1449	3.827	3.484	10
1050	16-Mar-90	1.208	0.1612	1.322	1.094	4.130	0.2212	4.286	3.973	2
1050	04-Apr-91	1.350	0.1181	1.490	1.225	3.942	0.1506	4.102	3.764	10
1050	03-Nov-92	1.389	0.0365	1.430	1.329	3.889	0.0458	3.964	3.837	10
1050	03-Nov-94	1.736	0.0957	1.883	1.616	3.487	0.1029	3.618	3.330	10
1060	03-Apr-90	1.550	0.3510	1.879	1.227	3.720	0.4122	4.099	3.334	6
1060	22-Apr-91	1.267	0.0321	1.327	1.224	4.045	0.0425	4.103	3.967	10
1060	23-Jul-93	1.319	0.0458	1.379	1.242	3.977	0.0596	4.079	3.901	10
1060	15-Dec-93	1.363	0.0534	1.423	1.279	3.921	0.0678	4.029	3.846	10
1060	22-Apr-94	1.367	0.0523	1.426	1.301	3.917	0.0662	4.000	3.842	10
1060	14-Jul-94	1.352	0.0433	1.413	1.308	3.935	0.0550	3.991	3.858	10
1060	25-Oct-94	1.402	0.0862	1.498	1.298	3.874	0.1073	4.004	3.755	10
1060	19-Jan-95	1.425	0.1066	1.562	1.318	3.846	0.1310	3.978	3.680	10
1060	20-Apr-95	1.433	0.1082	1.554	1.289	3.836	0.1329	4.016	3.689	10
1060	27-Jun-95	1.429	0.1465	1.614	1.258	3.844	0.1801	4.057	3.620	10
1068	25-Apr-90	1.103	0.0778	1.181	1.016	4.275	0.1132	4.403	4.162	8
1068	23-Oct-91	1.129	0.0979	1.233	1.022	4.239	0.1404	4.394	4.091	10
1068	26-May-93	1.222	0.0986	1.343	1.101	4.108	0.1341	4.276	3.946	10
1068	20-Dec-93	1.233	0.1249	1.375	1.106	4.096	0.1691	4.269	3.906	10
1068	20-Apr-94	1.406	0.2163	1.662	1.186	3.879	0.2691	4.155	3.566	10
1068	12-Jul-94	1.209	0.0666	1.299	1.130	4.125	0.0909	4.234	4.003	10
1068	27-Oct-94	1.192	0.1157	1.326	1.076	4.151	0.1598	4.312	3.968	10
1068	16-Jan-95	1.263	0.1750	1.444	1.083	4.060	0.2335	4.302	3.820	10
1068	19-Apr-95	1.224	0.1392	1.368	1.088	4.109	0.1894	4.295	3.914	10
1068	22-Jun-95	1.185	0.1087	1.339	1.078	4.161	0.1503	4.310	3.951	10
1077	31-Oct-90	1.192	0.0515	1.277	1.121	4.147	0.0708	4.247	4.032	10
1077	08-Nov-91	1.247	0.0844	1.359	1.152	4.075	0.1133	4.203	3.926	10
1077	05-May-93	1.249	0.0596	1.331	1.169	4.071	0.0800	4.179	3.962	10
1077	06-Jan-94	1.080	0.0988	1.186	0.945	4.311	0.1470	4.514	4.155	10
1077	19-Apr-94	1.196	0.0237	1.226	1.163	4.141	0.0327	4.187	4.100	10
1077	08-Jul-94	1.266	0.0341	1.315	1.201	4.047	0.0456	4.134	3.982	10
1077	14-Oct-94	1.321	0.1069	1.450	1.199	3.978	0.1384	4.137	3.813	10
1077	11-Jan-95	1.218	0.0402	1.278	1.130	4.112	0.0552	4.234	4.031	10
1077	17-Apr-95	1.328	0.1058	1.491	1.206	3.968	0.1359	4.128	3.763	10
1077	21-Jun-95	1.249	0.1185	1.396	1.122	4.074	0.1590	4.245	3.879	10
1094	20-Mar-90	0.875	0.0625	0.937	0.811	4.618	0.0905	4.700	4.527	6
1094	11-Apr-91	0.908	0.1086	1.024	0.781	4.556	0.1521	4.700	4.391	10
1094	14-Dec-92	0.879	0.0593	0.950	0.796	4.613	0.0849	4.700	4.506	10
1094	21-Jul-94	0.961	0.1263	1.093	0.799	4.489	0.1931	4.700	4.287	10
1096	26-Mar-90	2.119	0.2320	2.332	1.900	3.103	0.2210	3.313	2.901	4
1096	06-Dec-91	2.306	0.0393	2.376	2.250	2.925	0.0354	2.975	2.862	10

Table 3.7 Roughness Data (continued)

SHRP ID	Profile Date	ROUGHNESS: IRI				ROUGHNESS: PSI				No. of Data
		Mean	Std. Dev	Max	Min	Mean	Std. Dev	Max	Min	
		m/km	m/km	m/km	m/km	m/km	m/km	m/km	m/km	
1096	22-Dec-92	2.310	0.1401	2.478	2.157	2.923	0.1260	3.061	2.773	10
1096	04-Oct-94	2.327	0.2804	2.653	1.991	2.914	0.2516	3.221	2.626	10
1113	20-Apr-90	0.756	0.0428	0.806	0.701	4.700	0.0000	4.700	4.700	6
1113	18-Dec-91	0.917	0.1034	1.032	0.805	4.549	0.1518	4.700	4.378	10
1130	04-Apr-90	3.705	0.2336	3.966	3.340	1.857	0.1559	2.103	1.685	10
1130	18-Mar-92	3.748	0.2586	4.041	3.453	1.829	0.1699	2.024	1.638	10
1168	25-Apr-90	1.022	0.0646	1.100	0.923	4.396	0.0995	4.550	4.277	12
1168	22-Mar-91	1.123	0.1420	1.308	0.968	4.252	0.2042	4.477	3.991	10
1168	26-May-93	1.183	0.1468	1.350	0.998	4.166	0.2048	4.430	3.937	10
1168	21-Feb-95	1.469	0.1828	1.664	1.247	3.798	0.2220	4.072	3.564	10
1178	18-Apr-90	1.765	0.0302	1.799	1.733	3.454	0.0323	3.488	3.418	6
1178	18-Mar-92	2.459	0.0253	2.498	2.413	2.790	0.0219	2.829	2.756	10
1178	02-Jun-93	3.129	0.1467	3.301	2.977	2.257	0.1082	2.370	2.131	10
3579	23-Aug-90	1.293	0.0486	1.350	1.229	4.011	0.0638	4.096	3.937	6
3579	21-Mar-91	1.380	0.0920	1.492	1.225	3.902	0.1172	4.102	3.762	10
3579	17-Feb-93	1.410	0.0780	1.504	1.313	3.863	0.0965	3.985	3.748	10
3579	28-Oct-94	1.377	0.1500	1.564	1.198	3.910	0.1893	4.139	3.677	10
3729	30-Mar-90	1.525	0.0294	1.552	1.493	3.724	0.0347	3.761	3.691	4
3729	19-Apr-91	1.551	0.1200	1.708	1.427	3.695	0.1397	3.841	3.515	10
3729	19-Mar-92	1.630	0.1888	1.847	1.436	3.609	0.2132	3.830	3.367	10
3729	05-Aug-93	1.667	0.1544	1.914	1.498	3.565	0.1708	3.755	3.298	10
3729	07-Mar-95	2.076	0.1336	2.336	1.894	3.140	0.1277	3.319	2.897	10
3739	29-Mar-90	2.000	0.1408	2.183	1.825	3.215	0.1390	3.390	3.037	10
3739	18-Apr-91	2.173	0.0990	2.292	2.004	3.048	0.0932	3.208	2.937	10
3739	20-Mar-92	2.231	0.0748	2.329	2.105	2.993	0.0691	3.110	2.903	10
3739	06-Aug-93	2.535	0.0758	2.627	2.414	2.725	0.0643	2.828	2.647	10
3739	14-Dec-93	2.532	0.0355	2.602	2.470	2.727	0.0301	2.780	2.668	10
3739	22-Apr-94	2.565	0.1177	2.710	2.386	2.700	0.0990	2.853	2.579	10
3739	14-Jul-94	2.358	0.1794	2.576	2.122	2.881	0.1594	3.094	2.690	10
3875	22-Feb-91	1.051	0.0861	1.148	0.948	4.353	0.1295	4.509	4.208	10
9005	06-Apr-90	1.211	0.3378	1.555	0.871	4.159	0.4679	4.636	3.688	10
9005	12-Apr-91	1.413	0.2874	1.740	1.124	3.880	0.3577	4.243	3.481	10
9005	15-Dec-92	1.478	0.2713	1.756	1.211	3.797	0.3278	4.121	3.463	10
9005	03-Oct-94	1.800	0.2906	2.110	1.495	3.431	0.3087	3.759	3.106	10

Notes:

1. Mean, standard deviation, etc. are computed from IRI data along both wheel paths given in table MON_PROFILE_MASTER of LTPP IMS for all the "good" runs.
2. PSI values are computed by converting each IRI data using Equation 1.
3. Number of data points is the total number of observations along both wheel paths.

Longitudinal cracking in the wheel paths was considered fatigue cracking in its initial stage. Patching often indicates covered up cracking. Considering these factors, longitudinal cracking in the wheel paths and patching were also extracted, modified, and used in addition to alligator cracking. Analysis was conducted on three sets of cracking data computed in the following manner:

- alligator cracking alone (A),
- alligator cracking + longitudinal cracking (A+L), and
- alligator cracking + longitudinal cracking + patching (A+L+P).

Alligator table MON_DIS_AC_REV presents the length of longitudinal cracking in the wheel paths (meters) and area of patching (sq.m.) in three severity levels: low, medium, and high) or cracking areas (sq.m.), longitudinal cracking lengths (m), patching areas (sq.m.) in three severity levels were added to get respectively the total_alligator_area (sq.m.), total_long_length (m), and total_patching_area (sq.m.). The conversions of units of these total quantities from metric system (m and sq.m.) to percent wheel path (%wp) were completed according to the following equations:

$$Alligator\_cracking\ \ (\%wp) = \frac{total\_alligator\_area\ \ (sqm)}{231.648} x100 \tag{3.2}$$

$$Longitudinal\_cracking\ \ (\%wp) = \frac{total\_long\_length\ \ (m)}{304.8} x100 \tag{3.3}$$

$$Patching\ \ (\%wp) = \frac{total\_patching\_area\ \ (sqm)}{231.648} x100 \tag{3.4}$$

Table 3.8 presents extracted and modified cracking data for all the selected sections. It was found that patching is nil in all the observations except for section 1130. There are also several sections without any alligator cracking.

Table 3.8 Cracking Data

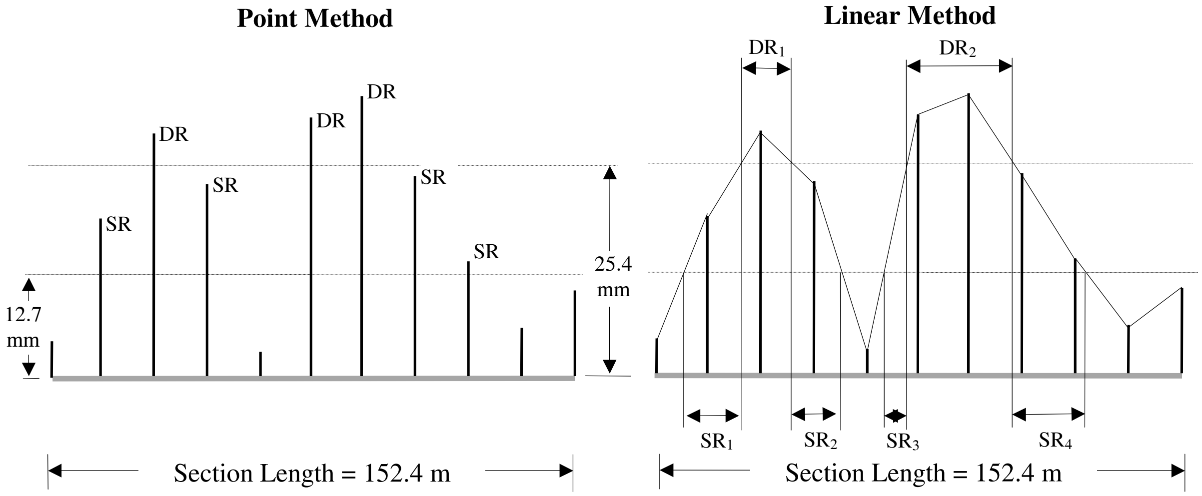
SHRP ID	Survey Date	Alli Crack	Long. Crack	Patch	Alli + Long	Alli+Long + Patch
		%WP	%WP	%WP	%WP	%WP
1047	11-Jun-91	0.00	1.12	0.00	1.12	1.12
1047	19-May-93	0.00	5.41	0.00	5.41	5.41
1047	10-Aug-95	0.00	5.41	0.00	5.41	5.41
1050	15-Nov-90	4.01	0.00	0.00	4.01	4.01
1050	28-May-91	1.12	13.09	0.00	14.21	14.21
1050	13-Jul-93	7.73	9.68	0.00	17.41	17.41
1050	24-Jul-95	22.62	5.22	0.00	27.84	27.84
1060	10-Apr-91	0.00	0.00	0.00	0.00	0.00
1060	26-Mar-92	0.00	1.21	0.00	1.21	1.21
1060	31-Mar-93	0.00	2.30	0.00	2.30	2.30
1060	11-Oct-94	0.00	1.41	0.00	1.41	1.41
1060	15-Mar-95	0.00	0.00	0.00	0.00	0.00
1060	20-Mar-95	0.00	1.41	0.00	1.41	1.41
1060	14-Jun-95	0.00	0.79	0.00	0.79	0.79
1068	26-Jun-91	0.00	3.71	0.00	3.71	3.71
1068	13-Aug-93	4.92	9.45	0.00	14.37	14.37
1068	27-Jan-95	7.04	26.90	0.00	33.94	33.94
1068	13-Apr-95	6.22	28.87	0.00	35.09	35.09
1068	08-Jun-95	6.22	28.87	0.00	35.09	35.09
1068	21-Jul-95	6.52	28.87	0.00	35.39	35.39
1077	07-Nov-91	0.00	0.00	0.00	0.00	0.00
1077	20-May-93	0.00	12.37	0.00	12.37	12.37
1077	24-Oct-94	0.39	14.34	0.00	14.73	14.73
1077	20-Apr-95	0.00	18.08	0.00	18.08	18.08
1077	22-Jun-95	0.00	18.08	0.00	18.08	18.08
1077	11-Aug-95	0.00	18.08	0.00	18.08	18.08
1077	25-Jun-96	0.00	18.08	0.00	18.08	18.08
1094	14-Aug-89	0.00	5.58	0.00	5.58	5.58
1094	27-Mar-91	0.00	3.61	0.00	3.61	3.61
1094	24-Sep-91	0.00	5.81	0.00	5.81	5.81
1094	05-Apr-93	0.00	4.36	0.00	4.36	4.36
1094	19-Sep-95	0.00	0.00	0.00	0.00	0.00
1096	26-Mar-91	0.00	7.19	0.00	7.19	7.19
1096	02-Apr-93	0.00	7.97	0.00	7.97	7.97
1096	23-Mar-95	0.00	66.50	0.00	66.50	66.50
1113	03-Jun-92	2.85	0.00	0.00	2.85	2.85
1130	25-Mar-91	21.41	1.51	0.00	22.92	22.92
1130	19-Mar-92	34.32	3.51	1.21	37.83	39.04
1168	24-Jun-91	1.38	1.61	0.00	2.99	2.99
1168	12-Aug-93	12.17	4.20	0.00	16.37	16.37
1168	20-Jul-95	15.93	6.46	0.00	22.39	22.39
1178	28-May-91	0.00	4.79	0.00	4.79	4.79
1178	13-Jul-93	0.00	9.45	0.00	9.45	9.45
1178	17-Mar-95	0.35	5.68	0.00	6.02	6.02
1178	11-May-95	0.00	0.00	0.00	0.00	0.00
3579	24-Jun-91	0.00	0.00	0.00	0.00	0.00
3579	21-Dec-92	0.00	0.00	0.00	0.00	0.00
3579	12-Aug-93	0.00	0.00	0.00	0.00	0.00
3579	07-Sep-94	0.00	0.00	0.00	0.00	0.00
3579	20-Jul-95	0.09	1.05	0.00	1.14	1.14
3729	09-Apr-91	0.00	15.91	0.00	15.91	15.91
3729	18-Mar-92	0.00	25.49	0.00	25.49	25.49
3729	30-Mar-93	1.86	21.92	0.00	23.77	23.77
3729	21-Mar-95	4.88	22.74	0.00	27.61	27.61
3739	09-Apr-91	0.00	0.98	0.00	0.98	0.98
3739	30-Aug-91	0.30	1.90	0.00	2.21	2.21
3739	18-Mar-92	1.81	8.30	0.00	10.11	10.11
3739	30-Mar-93	2.12	4.04	0.00	6.15	6.15
3875	12-Jun-91	0.00	0.00	0.00	0.00	0.00
9005	10-Oct-90	5.05	16.90	0.00	21.95	21.95
9005	27-Mar-91	0.78	21.49	0.00	22.27	22.27
9005	26-Aug-91	3.02	22.31	0.00	25.33	25.33
9005	05-Apr-93	2.33	0.00	0.00	2.33	2.33
9005	16-Feb-96	6.60	27.36	0.00	33.97	33.97
9005	09-Jul-96	10.14	25.30	0.00	35.44	35.44

Notes:

1. Cracking data is extracted from table MON_DIS_AC_REV of LTPP IMS and then modified.
2. Alli stands for alligator cracking.
3. Long stands for Longitudinal cracking in the wheel paths.
4. Cracking area and length are converted to percent wheel path using Equations 2 through 4.

Rutting: Table MON_RUT_DEPTHS of the LTPP IMS under data type monitoring contains rut depths (mm) along each wheel path. The status of this data is “A” and is not included in DataPave 97. Rutting data for the period 1989-96 were obtained from the regional office of LTPP. There are 11 readings at 15.2 m (50 ft) apart along each wheel path. Similar to roughness data, the number of rutting observations differs significantly from section to section. Rut data are not available for two sections, 1047 and 3875.

To convert rut data from depth in millimeters to area in percent wheel path under shallow rutting (SR) and deep rutting (DR) categories (as required for PMIS), two methods were applied. These two methods are illustrated in figure 3.2.



% Shallow rut =100 x 4/10 = 40
% Deep rut =100 x 3/10 = 30

% Shallow rut =$(SR_1+SR_2+SR_3+SR_4)$x100/152.4
% Deep rut =(DR_1+DR_2)x100/152.4

Figure 3.2 Methods for the Conversion of Rutting Data

In the first method, percent shallow and deep rutting were computed from the number of shallow (12.7 mm ≤ rut depth <25.4 mm) and deep ruts (rut depth ≥ 25.4 mm) out of 22 readings in each 152.4 m (500 ft) section. However, only rut depths along one wheel path are shown in figure 3.2 to make it more clear. The observations at the ends were considered as one-half reading. In the second method, linear variation of rut depth between two observations was used. Total length under each category was computed by linear interpolation and adding all segments along the two wheel paths. Shallow and deep rutting in percent wheel path were computed by dividing total lengths of shallow and deep rutting by total wheel path length (1000 ft) and then multiplying by 100. In addition, mean rut depth and variance of rut depth for each section were computed from the 22 readings in each section, which are presented in the summary data sheets.

Table 3.9 presents extracted and modified rut data for all the selected sections. It was found that rutting is less than 12.7 mm (0.5 inch) in most of the sections.

Traffic Data

Table TRF_EST_ANL_TOT_GPS_LN of the LTPP IMS under the broad data category traffic provides estimated two-way average annual daily traffic (AADT) and the number of equivalent 18-kip axle repetitions for each year from the year of opening to traffic. Data are generally available up to 1993, except for a few sections. Historical traffic data for the period from the date of opening to traffic to 1989 for all the LTPP sections (in Texas) were provided by TxDOT. Collecting traffic data through automated weight in motion (WIM) devices started in 1990. However, none of the sections selected has WIM data. TxDOT provided estimated traffic data for the selected sections.

Cumulative 18-kip equivalent single-axle load (ESAL) values for the 22-year period (starting from the date of opening to traffic) were computed by adding estimated annual ESAL for each year over the 20-year period. Annual ESALs were projected for the years for which no data were available. Future annual ESALs were estimated on the basis of the following considerations:

- Compute compound growth rate from the annual ESAL in the last available year and the annual ESAL two years before.
- If the computed growth rate is negative, the growth rate was zero.

Table 3.9 Rutting Data

SHRP ID	Survey Date	SHALLOW RUT		DEEP RUT		Mean Rut Depth	Var(Rut)
		Linear	Point	Linear	Point		
		%WP	%WP	%WP	%WP	inch	inch sq
1050	15-Nov-90	0.0	0.0	0.0	0.0	0.122	0.005
1050	28-May-91	0.0	0.0	0.0	0.0	0.156	0.007
1050	13-Jul-93	0.0	0.0	0.0	0.0	0.231	0.010
1060	10-Apr-91	0.0	0.0	0.0	0.0	0.129	0.007
1060	26-Mar-92	0.0	0.0	0.0	0.0	0.131	0.006
1068	26-Jun-91	0.0	0.0	0.0	0.0	0.095	0.003
1077	25-Jun-96	65.2	62.5	0.0	0.0	0.605	0.037
1094	14-Aug-89	0.0	0.0	0.0	0.0	0.021	0.002
1094	27-Mar-91	0.0	0.0	0.0	0.0	0.011	0.001
1094	24-Sep-91	0.0	0.0	0.0	0.0	0.011	0.001
1096	26-Mar-91	0.0	0.0	0.0	0.0	0.077	0.007
1113	25-Jun-91	0.0	0.0	0.0	0.0	0.177	0.005
1130	25-Mar-91	37.8	32.5	2.0	5.0	0.438	0.130
1130	19-Mar-92	44.5	40.0	4.6	10.0	0.589	0.097
1168	24-Jun-91	1.7	5.0	0.0	0.0	0.084	0.017
1178	28-May-91	0.0	0.0	0.0	0.0	0.054	0.004
1178	13-Jul-93	0.0	0.0	0.0	0.0	0.127	0.002
3579	24-Jun-91	0.0	0.0	0.0	0.0	0.041	0.004
3579	21-Dec-92	0.0	0.0	0.0	0.0	0.111	0.007
3579	20-Jul-95	0.0	0.0	0.0	0.0	0.197	0.005
3729	09-Apr-91	14.5	22.5	0.0	0.0	0.381	0.019
3729	18-Mar-92	34.3	30.0	0.0	0.0	0.451	0.023
3739	09-Apr-91	0.0	0.0	0.0	0.0	0.165	0.016
3739	30-Aug-91	0.0	0.0	0.0	0.0	0.247	0.010
3739	18-Mar-92	0.0	0.0	0.0	0.0	0.186	0.004
9005	10-Oct-90	0.0	0.0	0.0	0.0	0.039	0.005
9005	27-Mar-91	0.0	0.0	0.0	0.0	0.025	0.003
9005	16-Feb-96	0.0	0.0	0.0	0.0	0.104	0.014

Notes:

1. Rutting data is extracted from table MON_RUT_DEPTHS of LTPP IMS and then modified.
2. Record status of rut data is "A."
3. Rut depths are converted to percent shallow and deep rutting as shown in figure 2.3.

In addition, cumulative ESALs up to the dates of condition surveys were computed. Annual ESALs for a part-year (total number of ESAL from the first of January to the date of survey) were computed by proportion. Traffic data for several sections showed negative growths. The growth rate for section 3579 was computed as 43 percent using this approach. This growth rate gave a 20-year ESAL value of 32.8 million, an unreasonably high value. Considering past traffic, 469 kESAL in the first seven years, and the class of highway (SH0019), a growth rate of 5 percent per annum was assumed. The 20-year ESAL value was calculated as 1.792 million.

Table 3.10 presents extracted and modified traffic data for all the selected sections. Estimated 20-year ESALs of the selected sections vary between 0.037 and 4.2 million with an average value of 1 million. Figures B.1 to B.16 of Appendix B show the variation of annual ESAL and two-way ADT with respect to age of each section. In several sections it was found that percent truck traffic is decreasing while total traffic is increasing, resulting in a reverse trend between two-way ADT and annual ESAL.

Table 3.10 Traffic Data

SHRP ID	Traffic Open Date	AADT in the First Year	Estimated 20-Year ESAL
		Vpd	ESAL
1047	01-Sep-70	5420	5,993,000
1050	01-Jun-83	3600	651,000
1060	01-Mar-86	7800	1,822,000
1068	01-Jun-85	5500	1,666,000
1077	01-Jan-82	4800	4,165,000
1094	01-Nov-74	2280	243,000
1096	01-Jul-79	5900	1,126,000
1113	01-Jan-86	4700	1,738,000
1130	01-Oct-71	1620	842,000
1168	01-Sep-85	140	37,000
1178	01-Jul-88	6000	933,000
3579	01-Nov-87	2700	1,792,000
3729	01-Jun-83	20000	2,626,000
3739	01-May-82	4800	2,777,000
3875	01-Jun-84	3800	1,872,000
9005	01-Jul-86	1250	373,000

Elastic Modulus

Elastic moduli of pavement layers including subgrade are necessary input variables in FPS-19. The LTPP database does not provide layer modulus data. For this reason elastic moduli of pavement layers were back-calculated using the falling weight deflectometer (FWD) test results available in the LTPP database. The back-calculations were performed using the computer program MODULUS (11). The following tables of the LTPP IMS and FWD database under data category monitoring were used:

- MON_DEFL_DROP_DATA for deflection data,
- MON_DEFL_DEV_SENSORS for sensor locations for different configuration numbers,
- MON_DEFL_DEV_CONFIG for plate radius for different configuration numbers, and
- MON_DEFL_LOC_INFO for configuration number and pavement temperature.

Table MON_DEFL_DROP_DATA provides deflections (in microns) at seven sensor locations. FWD tests are generally conducted at 7.6 m (25 ft) intervals along the outer wheel path and between the wheel paths. At each location, there are 16 sets of data for 16 different drop loads. The oldest FWD data between the wheel paths were extracted assuming that these back-calculated moduli would be closest to that of the original construction section. Out of 16 drops, the first drop with a load between 8,000 and 10,000 lb and history **Y** was selected. It was found that there are several configurations where the second and third sensor are located at the same point (305 mm). These configuration numbers were checked against the configuration numbers used for the selected sections. Locations of the seven sensors (at 0.0 mm, 203 mm, 305 mm, 457 mm, 610 mm, 914 mm, and 1524 mm) and plate radius (150 mm) were found to be the same for all the selected sections.

Initially FWD drop data for all the sections were extracted to a text file. A small program was used for the following purposes:

- to select the particular drop, particular location (between wheel path), and particular date of survey;
- to convert the units; and
- to write the required data items according to the format of the OUT file (input file to the MODULUS program) in separate files for each section.

As recommended in the user's manual of the MODULUS program, a three-layer system was considered first for each section (11). However, for two sections (3579 and 3729), back-calculation required including a subbase layer below the base layer. The initial range of elastic modulus and Poisson's ratio for each layer were selected as recommended in the MODULUS user's manual (11). Average surface temperatures over the entire section were computed to determine the initial range of elastic modulus. In general, the surface temperatures recorded during FWD tests are lowest at the starting point and highest at the end point of the sections. The difference in maximum and minimum surface temperature was in the range from 1.7 °C to 5 °C (3-9 °F), except for section 1168, which had a difference of 8 °C (15 °F). Representative thicknesses of the layers were used for all the sections except for section 3729. According to table TST_L05B, section 3729 does not have a subbase layer, but the inventory data (table INV_LAYER) shows a 12-inch thick subbase layer. Moreover in section 3729, the elastic modulus of the base layer was back-calculated as 207 ksi without a subbase layer compared to 156 ksi with a 12-inch thick subbase layer. Therefore, it was decided that for the section 3729, the thicknesses given in table INV_LAYER would be used instead of representative thicknesses. All asphalt layer thicknesses were added to get the total AC thickness.

Table 3.11 presents back-calculated moduli, thicknesses and Poisson's ratios of each layer of all the selected sections. The average error per sensor was found in the range 0.82 - 4.77 percent in general. According to the user's manual of the MODULUS program, back-calculation with an average error per sensor of less than 4 percent can be considered satisfactory. For three sections (1094, 1113, and 1168) the percent errors were larger than 4 percent (7.3, 13.83, and 6.6) due to a difference in the observed and computed deflection at the seventh sensor, where the magnitude of deflection is very low. For a few sections, the out

Table 3.11 Back-Calculated Elastic Modulus

SHRP	FWD Test	LAYER THICKNESS				MEAN ELASTIC MODULUS				POISSON'S RATIO				SURFACE TEMP.			Average
ID	Date	AC	Base	Subbase	Subgrade	AC	Base	Subbase	Subgrade	AC	Base	Subbase	Subgrade	Min	Max	Avg	Error
		inch	inch	inch	inch	ksi	ksi	ksi	ksi					deg F	deg F	deg F	%
1047	7-Aug-89	10.1	15.3	[14.0]	145.7	546.0	23.5		19.0	0.35	0.35		0.4	64.4	69.8	67.2	1.18
1050	7-Jun-89	1.8	9.6	[6.5]	228.4	420.0	68.0		22.7	0.35	0.35		0.4	80.6	89.6	85.3	4.67
1060	5-Mar-90	7.5	12.3	[6.0]	300.0	1308.0	375.5		16.7	0.35	0.25		0.4	66.2	73.4	68.7	1.11
1068	23-Aug-89	10.9	6.0	[8.0]	145.1	362.0	37.7		18.9	0.35	0.35		0.4	86.0	91.4	88.1	0.82
1077	8-Aug-89	5.1	10.4	0.0	288.8	271.0	142.0		25.3	0.35	0.35		0.4	86.0	98.6	92.9	2.25
1094	7-Feb-90	1.9	8.4	0.0	77.0	1375.0	231.7		29.9	0.35	0.25		0.4	48.2	64.4	55.6	7.28
1096	12-Feb-90	7.1	8.1	0.0	183.1	1102.0	127.9		16.4	0.35	0.35		0.4	60.8	77.0	68.7	1.7
1113	2-Apr-90	1.5	11.5	0.0	45.1	700.0	57.0		22.6	0.35	0.35		0.4	69.8	80.6	73.9	13.83
1130	5-Feb-90	2.7	17.9	[8.0]	300.0	1612.0	34.9		22.9	0.35	0.35		0.4	32.0	44.6	36.0	4.62
1168	24-Aug-89	1.2	10.4	0.0	89.7	225.0	33.4		18.7	0.35	0.35		0.4	91.4	118.4	106.7	6.6
1178	9-Jun-89	8.5	10.8	[4.5]	300.0	639.0	224.0		23.5	0.35	0.25		0.4	77.0	89.6	84.3	1.49
3579	28-Aug-89	1.7	10.8	9.2	300.0	150.0	96.5	481.3	26.5	0.35	0.25	0.25	0.4	111.2	127.4	120.7	1.42
3729	23-Feb-90	10.0	10.0	12.0	300.0	1592.0	155.5	59.9	15.0	0.35	0.25	0.25	0.4	42.8	57.2	50.7	1.13
3739	26-Feb-90	1.8	11.4	[7.4]	257.4	650.0	81.7		15.1	0.35	0.35		0.4	71.6	78.8	75.4	4.77
3875	7-Nov-91	1.6	16.7	0.0	230.2	3850.0	102.5		38.5	0.35	0.25		0.4	26.6	19.4	24.7	4.48
9005	6-Feb-90	1.5	9.4	0.0	197.5	1300.0	138.6		28.4	0.35	0.25		0.4	53.6	62.6	58.2	4.22

Notes:

1. Back-calculation was performed using FWD data from the LTPP database. FWD data between wheel paths were used.
2. Poisson's ratios were assumed.
3. Thickness of pavement layers is from table TST_L05B. All asphalt layers were added to obtain total AC thickness.
4. Thickness of subbase within [ ] indicates that a three-layer system was considered for back-calculation.
5. Base and subbase thickness for section 3729 were taken from table INV_LAYER.
6. Minimum, maximum, and average temperatures are computed from temperatures at all the locations (25 ft apart) along each section.

deflections along the sections were found to vary significantly. The variation of deflection along the length of a section may be due to the variation in elastic moduli and/or thicknesses of the pavement layers and/or depth to rigid layer. Although in such situations a section is generally divided into more or less homogeneous subsections (with minor variation of deflections), this was not done since the condition data was only available for the entire 152.4 m (500 ft) section. Tables C.1 through C.16 of Appendix C present back-calculation summary reports for all the sections obtained as output from the MODULUS program.

PREDICTION USING PMIS AND FPS-19 MODELS

PMIS Models (12)

The PMIS uses pavement type, traffic class, treatment type, subgrade type, and 20-year ESAL to determine the parameters of the sigmoidal performance prediction model. It was necessary to determine values for these factors to calculate the model parameters (alpha, beta, etc.) (12).

Pavement Type

Flexible pavement types used in the PMIS are described in table 1 of reference 8. Total thicknesses of asphalt layers given in table 3.11 were used to determine the pavement type of each section. Of the 16 sections, eight sections were considered thin AC pavement (ACP06), six sections were considered thick AC pavement (ACP04), and the remaining two sections were considered intermediate AC pavement (ACP05).

Traffic Class

The PMIS uses the traffic classification given in table 3.12 to select the minimum ride score (RS_{min}) value. RS_{min} was used to compute the loss of ride quality using the sigmoidal model. ADT values given in table 3.12 are based on one-way values for divided facilities and two-way for undivided facilities. The LTPP database does not provide information on the divided/undivided characteristic of the sections. As a result, it was assumed that the sections with more than one lane in each direction are divided.

Number of lanes in each direction are given in table 3.5. Traffic data presented in table 3.10 were used to obtain the ADT. Eleven of 16 sections were considered high, for which the minimum ride score is 1.5. The remaining five sections were considered medium, for which the minimum ride score is 1.0.

Table 3.12 PMIS Traffic Classification

PMIS Traffic Class	Product of ADT and Speed Limit	ADT Range (for speed limit 55 mph)	Minimum Ride Score
Low	1 to 27,500	1 to 500	0.5
Medium	27,501 to 165,000	501 to 3,000	1.0
High	165,001 to 999,999	3001 to 999,999	1.5

ADT is one-way for divided road and two-way for undivided facility (clarified from Design Division,TxDOT)

Treatment Type

The PMIS uses four types of treatment as previously described. Since the selected sections are the original pavements (without any M&R), the performance models for heavy rehabilitation and reconstruction (Hrhb) treatment are the most appropriate for prediction. Therefore, the treatment type used for the prediction was Hrhb for all sections.

ESAL

The PMIS uses 20-year ESAL values to determine the Chi (χ) factors. Twenty-year ESAL values were computed from the estimated annual traffic data as explained in Chapter 2.

Subgrade Type

In PMIS, one subgrade type is assigned for each county within the state of Texas. The value of the sigma parameter depends on subgrade type as shown in table 3.13. Table 125 (of reference 8) was used to determine subgrade type from district and county names for each selected section. District and county names are available in table 3.4.

Table 3.13 PMIS Subgrade Classification

Subgrade Classification	**Value of Sigma**	
	For Distresses	For Ride Quality
Very Good	1.80	1.19
Good	1.61	1.14
Fair	1.42	1.08
Poor	1.21	1.04
Very Poor	1.00	1.00

The values of each factor for each section are summarized in table 3.14. The values of the model parameters (alpha, beta, and rho) corresponding to the pavement type, treatment type, and distress type (table 3.15), were taken from tables 129 through 135 of reference 8. Beta values for ride quality models were considered 2.0 for pavement types ACP4 through 10, in place of 20.0 given in reference 8. The traffic factors (Chi) corresponding to the pavement type and distress type were computed using values of Chi_{max}, Chi_{beta}, Chi_{rho}, and Chi_{min} given in tables 94 through 96 of reference 12. The values of the model parameter sigma corresponding to the subgrade type of each section (table 3.3), were taken from table 125 of reference 12. For each prediction, age was calculated as the period in years from the date of opening to traffic (table 3.6) to the date of condition survey.

The following PMIS performance models were used to determine the predicted conditions corresponding to the observed conditions:

- ride quality,
- alligator cracking,
- shallow rutting, and
- deep rutting.

Table 3.14 TxDOT-PMIS Performance Model Factors

SHRP ID	Pavement Type	Treatment Type	Traffic Class	20-Year ESAL	Subgrade Class
1047	ACP-04	Hrhb	High	5,993,000	Poor
1050	ACP-06	Hrhb	High	651,000	Poor
1060	ACP-04	Hrhb	High	1,822,000	Very Poor
1068	ACP-04	Hrhb	Medium	1,666,000	Poor
1077	ACP-05	Hrhb	High	4,165,000	Poor
1094	ACP-06	Hrhb	High	243,000	Very Good
1096	ACP-04	Hrhb	High	1,126,000	Good
1113	ACP-06	Hrhb	Medium	1,738,000	Fair
1130	ACP-05	Hrhb	High	842,000	Fair
1168	ACP-06	Hrhb	Medium	37,000	Fair
1178	ACP-04	Hrhb	High	933,000	Poor
3579	ACP-06	Hrhb	High	1,792,000	Poor
3729	ACP-04	Hrhb	High	2,626,000	Very Poor
3739	ACP-06	Hrhb	High	2,777,000	Poor
3875	ACP-06	Hrhb	Medium	1,872,000	Poor
9005	ACP-06	Hrhb	Medium	373,000	Very Good

Note:

1. All subgrade classes are taken from table-125 of reference 8.

Performance Predictions

Ride Quality

The performance model for ride quality predicts the loss of ride quality (L) from the selected initial value. Ride score (RS) was computed from the loss of ride quality (L) using the following equation:

$$L = \frac{4.8 - RS}{4.8 - RS_{\min}} \quad \textit{for}\ \mathrm{RS} \le 4.8, \ \text{and} \quad L = 0 \quad \textit{for}\ \mathrm{RS} > 4.8 \qquad (3.5)$$

where,

L = loss of ride quality (0-1),

RS = ride score, and

$RS_{\min}$ = minimum ride score, which depends on traffic classification given in table 3.12.

Table 3.15 Predicted Ride Quality Using TxDOT-PMIS Performance Model

SHRP ID	Opened to Traffic	Profile Date	Age	Pvmt Type	20-Year ESAL	PERFORMANCE MODEL PARAMETERS										RS_{min}	Loss of Ride Quality	Ride Quality
						Alpha	Beta	Rho	Chi_{max}	Chi_{beta}	Chi_{rho}	Chi_{min}	Chi	Epsilon	Sigma			
			years		million													
1047	01-Jul-71	29-Oct-90	19.3	4	5.993	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.114	1.000	1.040	1.5	0.790	2.192
1047	01-Jul-71	13-Nov-91	20.4	4	5.993	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.114	1.000	1.040	1.5	0.809	2.130
1047	01-Jul-71	07-May-93	21.9	4	5.993	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.114	1.000	1.040	1.5	0.832	2.055
1047	01-Jul-71	22-Nov-94	23.4	4	5.993	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.114	1.000	1.040	1.5	0.852	1.990
1050	01-Jul-85	16-Mar-90	4.7	6	0.651	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.119	1.000	1.040	1.5	0.001	4.796
1050	01-Jul-85	04-Apr-91	5.8	6	0.651	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.119	1.000	1.040	1.5	0.012	4.760
1050	01-Jul-85	03-Nov-92	7.3	6	0.651	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.119	1.000	1.040	1.5	0.066	4.581
1050	01-Jul-85	03-Nov-94	9.3	6	0.651	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.119	1.000	1.040	1.5	0.187	4.183
1060	01-Mar-86	03-Apr-90	4.1	4	1.822	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.007	4.776
1060	01-Mar-86	22-Apr-91	5.1	4	1.822	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.045	4.653
1060	01-Mar-86	23-Jul-93	7.4	4	1.822	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.222	4.066
1060	01-Mar-86	15-Dec-93	7.8	4	1.822	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.258	3.948
1060	01-Mar-86	22-Apr-94	8.1	4	1.822	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.289	3.845
1060	01-Mar-86	14-Jul-94	8.4	4	1.822	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.309	3.779
1060	01-Mar-86	25-Oct-94	8.7	4	1.822	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.334	3.699
1060	01-Mar-86	19-Jan-95	8.9	4	1.822	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.353	3.634
1060	01-Mar-86	20-Apr-95	9.1	4	1.822	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.374	3.567
1060	01-Mar-86	27-Jun-95	9.3	4	1.822	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.388	3.518
1068	01-Jun-87	25-Apr-90	2.9	4	1.666	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.0	0.000	4.800
1068	01-Jun-87	23-Oct-91	4.4	4	1.666	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.0	0.010	4.762
1068	01-Jun-87	26-May-93	6.0	4	1.666	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.0	0.084	4.482
1068	01-Jun-87	20-Dec-93	6.6	4	1.666	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.0	0.126	4.320
1068	01-Jun-87	20-Apr-94	6.9	4	1.666	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.0	0.153	4.217
1068	01-Jun-87	12-Jul-94	7.1	4	1.666	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.0	0.173	4.144
1068	01-Jun-87	27-Oct-94	7.4	4	1.666	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.0	0.198	4.049
1068	01-Jun-87	16-Jan-95	7.6	4	1.666	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.0	0.217	3.975
1068	01-Jun-87	19-Apr-95	7.9	4	1.666	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.0	0.239	3.891
1068	01-Jun-87	22-Jun-95	8.1	4	1.666	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.0	0.254	3.834
1077	01-Jan-82	31-Oct-90	8.8	5	4.165	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.086	1.000	1.040	1.5	0.307	3.787

Table 3.15 Predicted Ride Quality Using TxDOT-PMIS Performance Model (continued)

SHRP	Opened to	Profile	Age	Pvmt	20-Year	PERFORMANCE MODEL PARAMETERS										RS_{min}	Loss of	Ride
ID	Traffic	Date		Type	ESAL	Alpha	Beta	Rho	Chi_{max}	Chi_{beta}	Chi_{rho}	Chi_{min}	Chi	Epsilon	Sigma		Ride Quality	Quality
			years		million													
1077	01-Jan-82	08-Nov-91	9.9	5	4.165	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.086	1.000	1.040	1.5	0.387	3.522
1077	01-Jan-82	05-May-93	11.3	5	4.165	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.086	1.000	1.040	1.5	0.489	3.187
1077	01-Jan-82	06-Jan-94	12.0	5	4.165	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.086	1.000	1.040	1.5	0.528	3.056
1077	01-Jan-82	19-Apr-94	12.3	5	4.165	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.086	1.000	1.040	1.5	0.544	3.005
1077	01-Jan-82	08-Jul-94	12.5	5	4.165	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.086	1.000	1.040	1.5	0.556	2.966
1077	01-Jan-82	14-Oct-94	12.8	5	4.165	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.086	1.000	1.040	1.5	0.569	2.921
1077	01-Jan-82	11-Jan-95	13.0	5	4.165	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.086	1.000	1.040	1.5	0.581	2.882
1077	01-Jan-82	17-Apr-95	13.3	5	4.165	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.086	1.000	1.040	1.5	0.594	2.840
1077	01-Jan-82	21-Jun-95	13.5	5	4.165	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.086	1.000	1.040	1.5	0.602	2.813
1094	01-Aug-76	20-Mar-90	13.6	6	0.243	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.190	1.5	0.356	3.625
1094	01-Aug-76	11-Apr-91	14.7	6	0.243	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.190	1.5	0.411	3.443
1094	01-Aug-76	14-Dec-92	16.4	6	0.243	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.190	1.5	0.489	3.187
1094	01-Aug-76	21-Jul-94	18.0	6	0.243	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.190	1.5	0.552	2.978
1096	01-Apr-81	26-Mar-90	9.0	4	1.126	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.140	1.5	0.266	3.922
1096	01-Apr-81	06-Dec-91	10.7	4	1.126	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.140	1.5	0.392	3.506
1096	01-Apr-81	22-Dec-92	11.7	4	1.126	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.140	1.5	0.460	3.282
1096	01-Apr-81	04-Oct-94	13.5	4	1.126	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.140	1.5	0.557	2.962
1113	01-Jan-86	20-Apr-90	4.3	6	1.738	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.076	1.000	1.080	1.0	0.000	4.799
1113	01-Jan-86	18-Dec-91	6.0	6	1.738	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.076	1.000	1.080	1.0	0.016	4.738
1130	01-Aug-72	04-Apr-90	17.7	5	0.842	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.120	1.000	1.080	1.5	0.713	2.446
1130	01-Aug-72	18-Mar-92	19.6	5	0.842	1.000	2.000	8.500	1.12	0.50	11.20	0.94	1.120	1.000	1.080	1.5	0.760	2.291
1168	01-Sep-85	25-Apr-90	4.6	6	0.037	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.080	1.0	0.001	4.797
1168	01-Sep-85	22-Mar-91	5.6	6	0.037	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.080	1.0	0.006	4.777
1168	01-Sep-85	26-May-93	7.7	6	0.037	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.080	1.0	0.071	4.530
1168	01-Sep-85	21-Feb-95	9.5	6	0.037	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.080	1.0	0.172	4.147
1178	01-Jul-88	18-Apr-90	1.8	4	0.933	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.5	0.000	4.800
1178	01-Jul-88	18-Mar-92	3.7	4	0.933	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.5	0.002	4.795
1178	01-Jul-88	02-Jun-93	4.9	4	0.933	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.040	1.5	0.025	4.716
3579	01-Nov-87	23-Aug-90	2.8	6	1.792	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.073	1.000	1.040	1.5	0.000	4.800

Table 3.15 Predicted Ride Quality Using TxDOT-PMIS Performance Model (continued)

SHRP ID	Opened to Traffic	Profile Date	Age	Pvmt Type	20-Year ESAL	PERFORMANCE MODEL PARAMETERS										RS_{min}	Loss of Ride Quality	Ride Quality
						Alpha	Beta	Rho	Chi_{max}	Chi_{beta}	Chi_{rho}	Chi_{min}	Chi	Epsilon	Sigma			
			years		million													
3579	01-Nov-87	21-Mar-91	3.4	6	1.792	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.073	1.000	1.040	1.5	0.000	4.800
3579	01-Nov-87	17-Feb-93	5.3	6	1.792	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.073	1.000	1.040	1.5	0.008	4.773
3579	01-Nov-87	28-Oct-94	7.0	6	1.792	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.073	1.000	1.040	1.5	0.064	4.590
3729	01-Jun-83	30-Mar-90	6.8	4	2.626	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.172	4.234
3729	01-Jun-83	19-Apr-91	7.9	4	2.626	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.266	3.921
3729	01-Jun-83	19-Mar-92	8.8	4	2.626	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.346	3.658
3729	01-Jun-83	05-Aug-93	10.2	4	2.626	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.452	3.307
3729	01-Jun-83	07-Mar-95	11.8	4	2.626	1.000	2.000	8.100	1.12	0.63	27.58	0.94	1.120	1.000	1.000	1.5	0.552	2.978
3739	01-May-82	29-Mar-90	7.9	6	2.777	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.011	1.000	1.040	1.5	0.148	4.311
3739	01-May-82	18-Apr-91	9.0	6	2.777	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.011	1.000	1.040	1.5	0.226	4.054
3739	01-May-82	20-Mar-92	9.9	6	2.777	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.011	1.000	1.040	1.5	0.294	3.828
3739	01-May-82	06-Aug-93	11.3	6	2.777	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.011	1.000	1.040	1.5	0.390	3.513
3739	01-May-82	14-Dec-93	11.6	6	2.777	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.011	1.000	1.040	1.5	0.413	3.438
3739	01-May-82	22-Apr-94	12.0	6	2.777	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.011	1.000	1.040	1.5	0.435	3.366
3739	01-May-82	14-Jul-94	12.2	6	2.777	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.011	1.000	1.040	1.5	0.448	3.321
3875	01-Nov-85	22-Feb-91	5.3	6	1.872	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.068	1.000	1.040	1.0	0.009	4.766
9005	01-Sep-86	06-Apr-90	3.6	6	0.373	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.190	1.0	0.000	4.800
9005	01-Sep-86	12-Apr-91	4.6	6	0.373	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.190	1.0	0.000	4.800
9005	01-Sep-86	15-Dec-92	6.3	6	0.373	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.190	1.0	0.008	4.770
9005	01-Sep-86	03-Oct-94	8.1	6	0.373	1.000	2.000	10.400	1.12	0.50	4.24	0.94	1.120	1.000	1.190	1.0	0.053	4.598

Information on the factors affecting the model parameters provided in table 3.14 was used. Profile survey dates given in table 3.7 were used to calculate the ages. The predicted ride quality along with the loss in ride quality and the values of all model parameters are given in table 3.4. In total 78 predictions were performed for the 16 sections.

Alligator Cracking

The areas of alligator cracking in terms of percent wheel path were predicted for all the sections using the values of the model parameters and ages. Ages were calculated from the survey dates given in table 3.8. Table 3.16 presents the predicted areas of alligator cracking along with the values of the model parameters. In total, 72 predictions were performed for the 16 sections.

Shallow and Deep Rutting

Similar to alligator cracking, shallow and deep rutting in terms of percent wheel path were predicted using the sigmoidal form given in reference 12. Ages were calculated from the survey dates given in table 3.9. The predicted values of shallow and deep rutting along with the values of the model parameters are presented in tables 3.17 and 3.18, respectively.

FPS-19 Model

FPS-19 uses a serviceability model which predicts the loss of serviceability from the surface curvature index, number of 18-kip axle repetitions, and temperature. However, it does not report the terminal serviceability index. The output from FPS-19 contains performance periods, layer thicknesses (original and overlay), and life-cycle costs. Therefore, when the layer thicknesses are fixed (known), only the performance period (how long the given pavement will take to change from the initial condition to the terminal condition sustaining a given number of axle repetitions) can be determined. FPS-19 uses time as a surrogate for ESAL over the performance period. It computes the time (performance period) from the values of the initial and terminal ADT (r_0 and r_C), ESAL (N_C) over the design period, and the

Table 3.16 Predicted Alligator Cracking Using TxDOT-PMIS Performance Model

SHRP ID	Opened to Traffic	Survey Date	Age	Pvmt Type	20-Year ESAL	PERFORMANCE MODEL PARAMETERS										Alligator Cracking
						Alpha	Beta	Rho	Chi_{max}	Chi_{beta}	Chi_{rho}	Chi_{min}	Chi	Epsilon	Sigma	
			years		million											% wheel path
1047	01-Jul-71	11-Jun-91	20.0	4	5.993	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.294	1.000	1.210	62.840
1047	01-Jul-71	19-May-93	21.9	4	5.993	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.294	1.000	1.210	67.221
1047	01-Jul-71	10-Aug-95	24.1	4	5.993	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.294	1.000	1.210	71.376
1050	01-Jul-85	15-Nov-90	5.4	6	0.651	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.210	0.021
1050	01-Jul-85	28-May-91	5.9	6	0.651	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.210	0.074
1050	01-Jul-85	13-Jul-93	8.0	6	0.651	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.210	1.370
1050	01-Jul-85	24-Jul-95	10.1	6	0.651	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.210	5.328
1060	01-Mar-86	10-Apr-91	5.1	4	1.822	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	3.367
1060	01-Mar-86	26-Mar-92	6.1	4	1.822	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	7.933
1060	01-Mar-86	31-Mar-93	7.1	4	1.822	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	14.194
1060	01-Mar-86	11-Oct-94	8.6	4	1.822	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	24.593
1060	01-Mar-86	15-Mar-95	9.0	4	1.822	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	27.439
1060	01-Mar-86	20-Mar-95	9.1	4	1.822	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	27.530
1060	01-Mar-86	14-Jun-95	9.3	4	1.822	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	29.080
1068	01-Jun-87	26-Jun-91	4.1	4	1.666	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.210	0.103
1068	01-Jun-87	13-Aug-93	6.2	4	1.666	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.210	3.429
1068	01-Jun-87	27-Jan-95	7.7	4	1.666	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.210	9.428
1068	01-Jun-87	13-Apr-95	7.9	4	1.666	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.210	10.468
1068	01-Jun-87	08-Jun-95	8.0	4	1.666	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.210	11.255
1068	01-Jun-87	21-Jul-95	8.1	4	1.666	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.210	11.869
1077	01-Jan-82	07-Nov-91	9.9	5	4.165	100.000	1.690	8.400	1.30	2.34	15.37	0.70	1.242	1.000	1.210	21.898
1077	01-Jan-82	20-May-93	11.4	5	4.165	100.000	1.690	8.400	1.30	2.34	15.37	0.70	1.242	1.000	1.210	30.443
1077	01-Jan-82	24-Oct-94	12.8	5	4.165	100.000	1.690	8.400	1.30	2.34	15.37	0.70	1.242	1.000	1.210	37.764
1077	01-Jan-82	20-Apr-95	13.3	5	4.165	100.000	1.690	8.400	1.30	2.34	15.37	0.70	1.242	1.000	1.210	40.081
1077	01-Jan-82	22-Jun-95	13.5	5	4.165	100.000	1.690	8.400	1.30	2.34	15.37	0.70	1.242	1.000	1.210	40.879
1077	01-Jan-82	11-Aug-95	13.6	5	4.165	100.000	1.690	8.400	1.30	2.34	15.37	0.70	1.242	1.000	1.210	41.503
1077	01-Jan-82	25-Jun-96	14.5	5	4.165	100.000	1.690	8.400	1.30	2.34	15.37	0.70	1.242	1.000	1.210	45.310
1094	01-Aug-76	14-Aug-89	13.0	6	0.243	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	2.459
1094	01-Aug-76	27-Mar-91	14.7	6	0.243	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	4.776

Table 3.16 Predicted Alligator Cracking Using TxDOT-PMIS Performance Model (continued)

SHRP ID	Opened to Traffic	Survey Date	Age	Pvmt Type	20-Year ESAL	PERFORMANCE MODEL PARAMETERS										Alligator Cracking
						Alpha	Beta	Rho	Chi$_{max}$	Chi$_{beta}$	Chi$_{rho}$	Chi$_{min}$	Chi	Epsilon	Sigma	
			years		million											% wheel path
1094	01-Aug-76	24-Sep-91	15.2	6	0.243	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	5.640
1094	01-Aug-76	05-Apr-93	16.7	6	0.243	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	8.685
1094	01-Aug-76	19-Sep-95	19.1	6	0.243	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	14.409
1096	01-Apr-81	26-Mar-91	10.0	4	1.126	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.610	8.674
1096	01-Apr-81	02-Apr-93	12.0	4	1.126	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.610	16.689
1096	01-Apr-81	23-Mar-95	14.0	4	1.126	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.610	25.041
1113	01-Jan-86	03-Jun-92	6.4	6	1.738	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.218	1.000	1.420	0.064
1130	01-Aug-72	25-Mar-91	18.7	5	0.842	100.000	1.690	8.400	1.30	2.34	15.37	0.70	1.300	1.000	1.420	48.118
1130	01-Aug-72	19-Mar-92	19.6	5	0.842	100.000	1.690	8.400	1.30	2.34	15.37	0.70	1.300	1.000	1.420	51.144
1168	01-Sep-85	24-Jun-91	5.8	6	0.037	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.420	0.006
1168	01-Sep-85	12-Aug-93	8.0	6	0.037	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.420	0.325
1168	01-Sep-85	20-Jul-95	9.9	6	0.037	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.420	1.899
1178	01-Jul-88	28-May-91	2.9	4	0.933	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.210	0.001
1178	01-Jul-88	13-Jul-93	5.0	4	0.933	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.210	0.822
1178	01-Jul-88	17-Mar-95	6.7	4	0.933	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.210	5.214
1178	01-Jul-88	11-May-95	6.9	4	0.933	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.210	5.813
3579	01-Nov-87	24-Jun-91	3.6	6	1.792	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.210	1.000	1.210	0.000
3579	01-Nov-87	21-Dec-92	5.1	6	1.792	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.210	1.000	1.210	0.031
3579	01-Nov-87	12-Aug-93	5.8	6	1.792	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.210	1.000	1.210	0.132
3579	01-Nov-87	07-Sep-94	6.9	6	1.792	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.210	1.000	1.210	0.691
3579	01-Nov-87	20-Jul-95	7.7	6	1.792	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.210	1.000	1.210	1.710
3729	01-Jun-83	09-Apr-91	7.9	4	2.626	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	19.415
3729	01-Jun-83	18-Mar-92	8.8	4	2.626	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	25.830
3729	01-Jun-83	30-Mar-93	9.8	4	2.626	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	32.556
3729	01-Jun-83	21-Mar-95	11.8	4	2.626	100.000	1.690	8.100	1.30	3.16	37.35	0.70	1.300	1.000	1.000	43.883
3739	01-May-82	09-Apr-91	8.9	6	2.777	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.015	1.000	1.210	9.464
3739	01-May-82	30-Aug-91	9.3	6	2.777	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.015	1.000	1.210	11.159
3739	01-May-82	18-Mar-92	9.9	6	2.777	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.015	1.000	1.210	13.662
3739	01-May-82	30-Mar-93	10.9	6	2.777	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.015	1.000	1.210	18.585

Table 3.16 Predicted Alligator Cracking using TxDOT-PMIS Performance Model (continued)

SHRP ID	Opened to Traffic	Survey Date	Age	Pvmt Type	20-Year ESAL	PERFORMANCE MODEL PARAMETERS										Alligator Cracking
						Alpha	Beta	Rho	Chi$_{max}$	Chi$_{beta}$	Chi$_{rho}$	Chi$_{min}$	Chi	Epsilon	Sigma	
			years		million											% wheel path
3875	01-Nov-85	12-Jun-91	5.6	6	1.872	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.196	1.000	1.210	0.107
9005	01-Sep-86	10-Oct-90	4.1	6	0.373	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	0.000
9005	01-Sep-86	27-Mar-91	4.6	6	0.373	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	0.000
9005	01-Sep-86	26-Aug-91	5.0	6	0.373	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	0.000
9005	01-Sep-86	05-Apr-93	6.6	6	0.373	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	0.001
9005	01-Sep-86	16-Feb-96	9.5	6	0.373	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	0.171
9005	01-Sep-86	09-Jul-96	9.9	6	0.373	100.000	1.690	12.100	1.30	2.31	5.81	0.70	1.300	1.000	1.800	0.262

Table 3.17 Predicted Shallow Rutting Using TxDOT-PMIS Performance Model

SHRP ID	Opened to Traffic	Survey Date	Age	20-Year ESAL	PERFORMANCE MODEL PARAMETERS										Shallow Rutting
					Alpha	Beta	Rho	Chi$_{max}$	Chi$_{beta}$	Chi$_{rho}$	Chi$_{min}$	Chi	Epsilon	Sigma	
			years	million											% wheel path
1050	01-Jul-85	15-Nov-90	5.4	0.651	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.180	1.000	1.210	0.0
1050	01-Jul-85	28-May-91	5.9	0.651	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.180	1.000	1.210	0.1
1050	01-Jul-85	13-Jul-93	8.0	0.651	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.180	1.000	1.210	4.0
1060	01-Mar-86	10-Apr-91	5.1	1.822	100.000	2.550	5.800	1.18	1.48	33.28	0.83	1.180	1.000	1.000	12.2
1060	01-Mar-86	26-Mar-92	6.1	1.822	100.000	2.550	5.800	1.18	1.48	33.28	0.83	1.180	1.000	1.000	25.8
1068	01-Jun-87	26-Jun-91	4.1	1.666	100.000	2.550	5.800	1.18	1.48	33.28	0.83	1.180	1.000	1.210	0.2
1077	01-Jan-82	25-Jun-96	14.5	4.165	100.000	2.550	6.600	1.18	1.14	13.56	0.83	1.136	1.000	1.210	73.9
1094	01-Aug-76	14-Aug-89	13.0	0.243	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.180	1.000	1.800	7.6
1094	01-Aug-76	27-Mar-91	14.7	0.243	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.180	1.000	1.800	14.8
1094	01-Aug-76	24-Sep-91	15.2	0.243	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.180	1.000	1.800	17.3
1096	01-Apr-81	26-Mar-91	10.0	1.126	100.000	2.550	5.800	1.18	1.48	33.28	0.83	1.180	1.000	1.610	27.7
1113	01-Jan-86	25-Jun-91	5.5	1.738	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.121	1.000	1.420	0.0
1130	01-Aug-72	25-Mar-91	18.7	0.842	100.000	2.550	6.600	1.18	1.14	13.56	0.83	1.180	1.000	1.420	76.8
1130	01-Aug-72	19-Mar-92	19.6	0.842	100.000	2.550	6.600	1.18	1.14	13.56	0.83	1.180	1.000	1.420	79.4
1168	01-Sep-85	24-Jun-91	5.8	0.037	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.180	1.000	1.420	0.0
1178	01-Jul-88	28-May-91	2.9	0.933	100.000	2.550	5.800	1.18	1.48	33.28	0.83	1.180	1.000	1.210	0.0
1178	01-Jul-88	13-Jul-93	5.0	0.933	100.000	2.550	5.800	1.18	1.48	33.28	0.83	1.180	1.000	1.210	2.9
3579	01-Nov-87	24-Jun-91	3.6	1.792	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.115	1.000	1.210	0.0
3579	01-Nov-87	21-Dec-92	5.1	1.792	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.115	1.000	1.210	0.0
3579	01-Nov-87	20-Jul-95	7.7	1.792	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.115	1.000	1.210	4.6
3729	01-Jun-83	09-Apr-91	7.9	2.626	100.000	2.550	5.800	1.18	1.48	33.28	0.83	1.180	1.000	1.000	49.5
3729	01-Jun-83	18-Mar-92	8.8	2.626	100.000	2.550	5.800	1.18	1.48	33.28	0.83	1.180	1.000	1.000	59.1
3739	01-May-82	09-Apr-91	8.9	2.777	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.002	1.000	1.210	19.9
3739	01-May-82	30-Aug-91	9.3	2.777	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.002	1.000	1.210	23.6
3739	01-May-82	18-Mar-92	9.9	2.777	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.002	1.000	1.210	28.7
9005	01-Sep-86	10-Oct-90	4.1	0.373	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.180	1.000	1.800	0.0
9005	01-Sep-86	27-Mar-91	4.6	0.373	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.180	1.000	1.800	0.0
9005	01-Sep-86	16-Feb-96	9.5	0.373	100.000	2.550	8.900	1.18	1.13	5.13	0.83	1.180	1.000	1.800	0.3

Table 3.18 Predicted Deep Rutting Using TxDOT-PMIS Performance Model

SHRP	Opened to	Survey	Age	20-Year	PERFORMANCE MODEL PARAMETERS										Deep
ID	Traffic	Date		ESAL	Alpha	Beta	Rho	Chi$_{max}$	Chi$_{beta}$	Chi$_{rho}$	Chi$_{min}$	Chi	Epsilon	Sigma	Rutting
			years	million											% wheel path
1050	01-Jul-85	15-Nov-90	5.4	0.651	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.180	1.000	1.210	2.8
1050	01-Jul-85	28-May-91	5.9	0.651	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.180	1.000	1.210	3.9
1050	01-Jul-85	13-Jul-93	8.0	0.651	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.180	1.000	1.210	9.2
1060	01-Mar-86	10-Apr-91	5.1	1.822	100.000	1.000	13.450	1.18	1.48	33.28	0.83	1.180	1.000	1.000	4.5
1060	01-Mar-86	26-Mar-92	6.1	1.822	100.000	1.000	13.450	1.18	1.48	33.28	0.83	1.180	1.000	1.000	7.3
1068	01-Jun-87	26-Jun-91	4.1	1.666	100.000	1.000	13.450	1.18	1.48	33.28	0.83	1.180	1.000	1.210	0.9
1077	01-Jan-82	25-Jun-96	14.5	4.165	100.000	1.000	13.450	1.18	1.14	13.56	0.83	1.136	1.000	1.210	27.9
1094	01-Aug-76	14-Aug-89	13.0	0.243	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.180	1.000	1.800	11.2
1094	01-Aug-76	27-Mar-91	14.7	0.243	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.180	1.000	1.800	14.2
1094	01-Aug-76	24-Sep-91	15.2	0.243	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.180	1.000	1.800	15.2
1096	01-Apr-81	26-Mar-91	10.0	1.126	100.000	1.000	13.450	1.18	1.48	33.28	0.83	1.180	1.000	1.610	7.7
1113	01-Jan-86	25-Jun-91	5.5	1.738	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.121	1.000	1.420	2.0
1130	01-Aug-72	25-Mar-91	18.7	0.842	100.000	1.000	13.450	1.18	1.14	13.56	0.83	1.180	1.000	1.420	29.9
1130	01-Aug-72	19-Mar-92	19.6	0.842	100.000	1.000	13.450	1.18	1.14	13.56	0.83	1.180	1.000	1.420	31.8
1168	01-Sep-85	24-Jun-91	5.8	0.037	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.180	1.000	1.420	2.1
1178	01-Jul-88	28-May-91	2.9	0.933	100.000	1.000	13.450	1.18	1.48	33.28	0.83	1.180	1.000	1.210	0.1
1178	01-Jul-88	13-Jul-93	5.0	0.933	100.000	1.000	13.450	1.18	1.48	33.28	0.83	1.180	1.000	1.210	2.2
3579	01-Nov-87	24-Jun-91	3.6	1.792	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.115	1.000	1.210	0.7
3579	01-Nov-87	21-Dec-92	5.1	1.792	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.115	1.000	1.210	2.9
3579	01-Nov-87	20-Jul-95	7.7	1.792	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.115	1.000	1.210	9.5
3729	01-Jun-83	09-Apr-91	7.9	2.626	100.000	1.000	13.450	1.18	1.48	33.28	0.83	1.180	1.000	1.000	13.3
3729	01-Jun-83	18-Mar-92	8.8	2.626	100.000	1.000	13.450	1.18	1.48	33.28	0.83	1.180	1.000	1.000	16.5
3739	01-May-82	09-Apr-91	8.9	2.777	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.002	1.000	1.210	16.2
3739	01-May-82	30-Aug-91	9.3	2.777	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.002	1.000	1.210	17.4
3739	01-May-82	18-Mar-92	9.9	2.777	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.002	1.000	1.210	19.2
9005	01-Sep-86	10-Oct-90	4.1	0.373	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.180	1.000	1.800	0.1
9005	01-Sep-86	27-Mar-91	4.6	0.373	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.180	1.000	1.800	0.2
9005	01-Sep-86	16-Feb-96	9.5	0.373	100.000	1.000	13.450	1.18	1.13	5.13	0.83	1.180	1.000	1.800	4.9

predicted ESAL (N_e) corresponding to a reliability level. In this computation, FPS-19 assumes a uniform growth of traffic (from r_0 to r_C) as shown in figure 3.3.

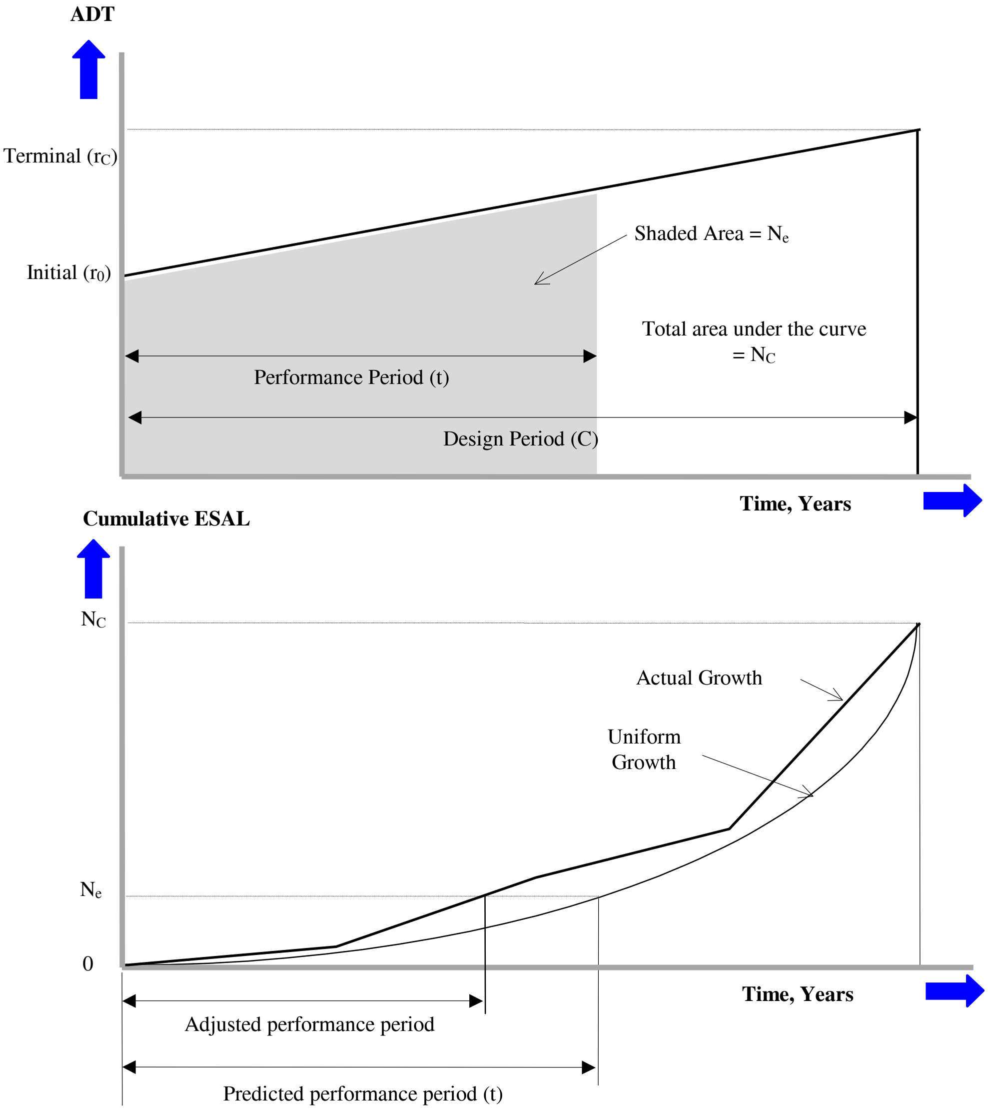


Figure 3.3 Adjusted Performance Period

The area under the ADT versus time line shown in figure 3.3 represents the cumulative ESAL. The performance period (along the time axis) is the base of the shaded area that represents the expected ESAL (N_e). It is apparent from the figure that if the top line of the shaded area changes (becomes curved or broken) then the base of the trapezium should be changed in order to get the same area. In such cases, performance periods can be adjusted from the annual cumulative ESAL data (additional data, not required in FPS-19) and the expected ESAL values as shown in figure 3.3.

Since the traffic growth rates on the selected sections are not uniform, the performance period obtained from FPS-19 cannot be used for evaluation. Therefore, it was decided that the predicted ESALs would be compared with the observed ESALs.

FPS-19 does not provide the average prediction. The minimum reliability is 80 percent, which is at level A. In addition, FPS-19 does not provide any solution when the predicted performance period is less than one year. It also truncates the performance periods of those that are more than 40 years or cross a 40-year period from the start of the first performance period. As a result, when FPS-19 displays a performance period as 40 years, the performance period corresponding to the expected ESAL (N_e) is more than or equal to 40 years. Considering this problem, it was decided that predictions would be completed at all reliability levels, and from those the average prediction would be back-calculated.

FPS-19 uses several constraints to arrive at the most desired solution. It does not provide any solution if there is any conflict. Therefore, it was necessary to eliminate the constraints to ensure a successful run. For example, the input variable “minimum time to the first overlay” was held constant at one year. This was done because if the predicted performance period was five years and the minimum time to the first overlay was 10 years, FPS-19 would not produce a solution.

FPS-19 requires cost data to determine the option with the least life-cycle cost. To determine this cost data, material cost, traffic diversion type, percent trucks, etc. are used. Since pavement design was not the objective, typical values were assigned to the unimportant input variables.

FPS-19 uses certain data items (probability of swelling, potential vertical rise, etc.) to determine the loss of serviceability due to swelling soil. In line with the objectives of this study, the loss of serviceability due to swelling soil was not considered by assigning zero values to the swelling input data.

Performance Prediction

The expected number of 18-kip axle repetitions (N_e) was considered the predicted variable and was back-calculated using the following equation:

$$N_e = \frac{N_c}{C(r_o + r_C)}\left(2r_o t + \frac{(r_C - r_o)t^2}{C}\right) \tag{3.6}$$

where,

N_e = expected cumulative 18-kip ESAL, computed using Equation 3.6;

N_C = estimated cumulative 18-kip ESAL over the design period, input to FPS 19;

t = performance period (years), output from FPS 19;

r_o = initial ADT vehicles per day (vpd), input to FPS 19;

r_C = ADT at the end of design period (vpd), input to FPS 19; and

C = design period (years), input to FPS 19.

For example, if the estimated ESAL (N_c) is 2 million over the design period (C) of 20 years and the ADT at the start (r_0) and at the end (r_C) of the design period are 2000 vpd and 4000 vpd, respectively, then the performance period (t) corresponding to an expected ESAL (N_e as predicted from serviceability and reliability criteria) of 0.5 million will be around 6.4 years according to Equation 3.6. Since this performance period is less than the design period, one or more overlays may be required to cover the design period. Performance periods for each overlay are computed in the same way.

In all the runs, the design period was held constant at 20 years. The 20-year ESAL and the initial ADT were taken from table 3.19. Since computation of the expected ESAL (N_e) depends on the ratio of the terminal ADT (r_C) to the initial ADT (r_o) and not on the absolute ADT figures, the terminal ADT values were considered twice the values of the initial ADT (r_C/r_o=2).

The initial SI values are not available in the LTPP database. As a result, the following values were assumed for the initial SI:

- 4.5 for pavement type ACP04 and ACP05, and
- 4.2 for pavement type ACP06.

The terminal SI values used were the observed PSI values given in table 3.7.

FPS-19 uses a default value for the mean daily temperature (T) for each district in Texas. Although the user can modify this default value during data entry, our calculators used the PMIS district numbers given in table 3.4 to accept the default values of FPS-19.

Elastic moduli of the pavement layers given in table 3.11 were back-calculated from FWD tests conducted at various temperatures. FPS-19 uses elastic modulus at the standard temperature of 70 °F. Since the variation of elastic modulus of granular and fine-grained materials is insignificant, no corrections were applied for elastic moduli of the base and subgrade. However, elastic moduli of AC layers were corrected to 70 °F by multiplying the back-calculated moduli by a correction factor. The correction factors were computed using the following equation (12):

$$\mathbf{CF} = \frac{\mathbf{T}^{2.81}}{185000} \text{ for } 50 \le \mathrm{T} \le 110 \tag{3.7}$$

where,

CF = correction factor in the range 0.32 to 0.95, and
T = observed temperature in °F.

Thickness and Poisson's ratio of pavement layers were taken from table 3.11.

FPS-19 uses different design types as already discussed in the previous chapters. It was observed that FPS-19 can provide erroneous results if the appropriate design type is not chosen. Design types 1 and 4 were considered respectively for all three-layer and four-layer systems.

Table 3.19 presents all relevant input and output data to/from FPS-19. The results in table 3.19 show that for several sections, the same performance periods were obtained for a

Table 3.19 Input to and Output from FPS-19

INPUT TO FPS-19																				OUTPUT FROM FPS-19				
SHRP	Design	S I		ADT		20-Year	District	AC			BASE			SUBBASE			SUBGRADE			1ST PERFORMANCE PERIOD				
ID	Type	Initial	Final	Initial	Final	ESAL	Temp	D	E	Mu	D	E	Mu	D	E	Mu	D	E	Mu	RL-A	RL-B	RL-C	RL-D	RL-E
				vpd	vpd	million	deg F	inch	ksi		inch	ksi		inch	ksi		inch	ksi		years	years	years	years	years
1047	1	4.5	3.135	5420	10840	5.993	16	10.1	402.7	0.35	15.3	23.5	0.35				145.7	19.0	0.40	19	17	9	4	2
1047		4.5	3.133																	19	17	9	4	2
1047		4.5	3.055																	19	17	9	4	2
1050	1	4.2	4.130	3600	7200	0.651	30	1.8	605.4	0.35	9.6	68.0	0.35				228.4	22.7	0.40	NS	NS	NS	NS	NS
1050		4.2	3.942			0.651														8	6	2	NS	NS
1050		4.2	3.889			0.651														8	6	2	NS	NS
1050		4.2	3.487			0.651														26	22	11	5	2
1060	1	4.5	3.720	7800	15600	1.822	36	7.5	1026.3	0.35	12.3	375.5	0.25				300.0	16.7	0.40	40	40	40	40	23
1060		4.5	4.045			1.822														40	40	40	22	8
1060		4.5	3.977			1.822														40	40	40	22	8
1060		4.5	3.921			1.822														40	40	40	31	13
1060		4.5	3.917			1.822														40	40	40	31	13
1060		4.5	3.935			1.822														40	40	40	31	13
1060		4.5	3.874			1.822														40	40	40	31	13
1060		4.5	3.846			1.822														40	40	40	40	18
1060		4.5	3.836			1.822														40	40	40	40	18
1060		4.5	3.844			1.822														40	40	40	40	18
1068	1	4.5	4.275	5500	11000	1.666	21	10.9	571.4	0.35	6.0	37.7	0.35				145.1	18.9	0.40	7	4	NS	NS	NS
1068		4.5	4.239			1.666														18	13	3	NS	NS
1068		4.5	4.108			1.666														28	22	8	3	NS
1068		4.5	4.096			1.666														28	22	8	3	NS
1068		4.5	3.879			1.666														40	38	19	8	3
1068		4.5	4.125			1.666														28	22	8	3	NS
1068		4.5	4.151			1.666														18	13	3	NS	NS
1068		4.5	4.060			1.666														28	22	8	3	NS
1068		4.5	4.109			1.666														28	22	8	3	NS
1068		4.5	4.161			1.666														18	13	3	NS	NS
1077	1	4.5	4.147	4800	9600	4.165	19	5.1	496.5	0.35	10.4	142.0	0.35				288.8	25.3	0.40	9	7	2	NS	NS
1077		4.5	4.075			4.165														9	7	2	NS	NS

Table 3.19 Input to and Output from FPS-19 (continued)

INPUT TO FPS-19																				OUTPUT FROM FPS-19				
SHRP	Design	S I		ADT		20-Year	District	AC			BASE			SUBBASE			SUBGRADE			1ST PERFORMANCE PERIOD				
ID	Type	Initial	Final	Initial	Final	ESAL	Temp	D	E	Mu	D	E	Mu	D	E	Mu	D	E	Mu	RL-A	RL-B	RL-C	RL-D	RL-E
				vpd	vpd	million	deg F	inch	ksi		inch	ksi		inch	ksi		inch	ksi		years	years	years	years	years
1077		4.5	4.311			4.165														2	1	NS	NS	NS
1077		4.5	4.141			4.165														9	7	2	NS	NS
1077		4.5	4.047			4.165														13	10	4	1	NS
1077		4.5	3.978			4.165														13	10	4	1	NS
1077		4.5	4.112			4.165														9	7	2	NS	NS
1077		4.5	3.968			4.165														13	10	4	1	NS
1077		4.5	4.074			4.165														9	7	2	NS	NS
1094		4.2	4.618			0.243		1.9	595.4	0.35	8.4	231.7	0.25				77.0	29.9	0.40					
1094		4.2	4.556			0.243																		
1094		4.2	4.613			0.243																		
1094		4.2	4.489			0.243																		
1096	1	4.5	3.103	5900	11800	1.126	31	7.1	864.7	0.35	8.1	127.9	0.35				183.1	16.4	0.40	40	40	40	40	23
1096		4.5	2.925			1.126														40	40	40	40	26
1096		4.5	2.923			1.126														40	40	40	40	26
1096		4.5	2.914			1.126														40	40	40	40	26
1113		4.2	4.700			1.738		1.5	674.2	0.35	11.5	57.0	0.35				45.1	22.6	0.40					
1113		4.2	4.549			1.738																		
1130	1	4.5	1.857	1620	3240	0.842	31	2.7	518.0	0.35	17.9	34.9	0.35				300.0	22.9	0.40	40	40	30	17	8
1130		4.5	1.829			0.842														40	40	30	17	9
1168		4.2	4.396			0.037		1.2	608.3	0.35	10.4	33.4	0.35				89.7	18.7	0.40					
1168		4.2	4.252			0.037																		
1168		4.2	4.166			0.037																		
1168		4.2	3.798			0.037																		
1178	1	4.5	3.454	6000	12000	0.933	30	8.5	891.1	0.35	10.8	224.0	0.35				300.0	23.5	0.40	40	40	40	40	39
1178		4.5	2.790			0.933														40	40	40	40	40
1178		4.5	2.257			0.933														40	40	40	40	40
3579	4	4.2	4.011	2700	5400	1.792	24	1.7	441.8	0.35	10.8	96.5	0.25	9.2	481.3	0.25	300.0	26.5	0.40	5	3	NS	NS	NS
3579		4.2	3.902			1.792														12	9	3	NS	NS
3579		4.2	3.910			1.792														12	9	3	NS	NS

Table 3.19 Input to and Output from FPS-19 (continued)

INPUT TO FPS-19																				OUTPUT FROM FPS-19				
SHRP	Design	S I		ADT		20-Year	District	AC			BASE			SUBBASE			SUBGRADE			1ST PERFORMANCE PERIOD				
ID	Type	Initial	Final	Initial	Final	ESAL	Temp	D	E	Mu	D	E	Mu	D	E	Mu	D	E	Mu	RL-A	RL-B	RL-C	RL-D	RL-E
				vpd	vpd	million	deg F	inch	ksi		inch	ksi		inch	ksi		inch	ksi		years	years	years	years	years
3729	4	4.5	3.724	20000	40000	2.626	38	10.0	531.9	0.35	10.0	155.5	0.25	12.0	59.9	0.25	300.0	15.0	0.40	40	40	40	26	12
3729		4.5	3.695			2.626														40	40	40	26	12
3729		4.5	3.609			2.626														40	40	40	30	14
3729		4.5	3.565			2.626														40	40	40	30	14
3729		4.5	3.140			2.626														40	40	40	40	25
3739	1	4.2	3.215	4800	9600	2.777	38	1.8	662.5	0.35	11.4	81.7	0.35				257.4	15.1	0.40	18	15	8	4	2
3739		4.2	3.048			2.777														20	18	10	5	2
3739		4.2	2.993			2.777														20	18	10	5	2
3739		4.2	2.725			2.777														24	21	12	6	3
3739		4.2	2.727			2.777														24	21	12	6	3
3739		4.2	2.700			2.777														24	21	12	6	3
3739		4.2	2.881			2.777														22	19	10	5	2
3875		4.2	4.353			1.872		1.6	1237.1	0.35	16.7	102.5	0.25				230.2	38.5	0.40					
9005	1	4.2	4.159	1250	2500	0.373	31	1.5	640.0	0.35	9.4	138.6	0.25				197.5	28.4	0.40	NS	NS	NS	NS	NS
9005		4.2	3.880			0.373														31	24	8	2	NS
9005		4.2	3.797			0.373														40	38	17	6	2
9005		4.2	3.431			0.373														40	40	40	25	12

Notes:

1. D, E, and Mu stand for thickness, elastic modulus, and Poisson's Ratio, respectively.
2. RL stands for reliability level.

small variation of the terminal SI. For example in section 1050, the first performance periods for reliability level A corresponding to the terminal SI of 3.937 and 3.888 were both eight years. This is because FPS-19 accepts SI values only up to the first place after the decimal. So the terminal SI values were rounded to the first place after the decimal (3.9 in place of 3.937 and 3.888 of the previous example). The results given in table 3.19 also show that there were several runs without any solution (marked as NS in the performance period field). There were also several runs where FPS-19 indicated a performance period of 40 years. FPS-19 could not be run for four sections (1094, 1113, 1168, and 3875) where most of the observed terminal SI values are higher than the assumed initial SI values. For example, the initial SI for section 1094 was considered 4.2 (due to a thin AC surface), whereas all the observed terminal SI values were more than 4.4.

The back-calculated expected ESALs corresponding to the first performance periods are given in table 3.20. The expected ESALs corresponding to the performance periods with a no solution (NS) remark or a 40-year value could not be back-calculated due to the lack of distinctness of such performance period values.

EVALUATION OF PERFORMANCE MODELS

The TxDOT PMIS performance models were empirically developed from observed data using several simplifying assumptions (12). Differences between the observed and predicted data were expected. Some of the differences are due to differences in measuring and computing observed values. The observed values must be considered estimates rather than true values. Therefore, a performance model cannot be rejected simply because some predicted values are not equal to the observed values. The main concerns are how good the model is and whether the model can be used for its intended purpose.

At network level, a performance model should predict with sufficient accuracy that costs for a group of pavements do not significantly change. For example, if an agency assigns preventive maintenance, light rehabilitation, and medium rehabilitation treatments for PSI ranges of 3.5-4.0, 3.0-3.5, and 2.5-3.0, respectively, then a model predicting PSI should not predict a value so that preventive maintenance or medium rehabilitation treatment is assigned in place of light rehabilitation treatment that would have been selected if the actual PSI were known. However, this does not include PSI values near the boundary between two treatment

Table 3.20 Predicted ESAL Cumulative Up to the Date of Survey

SHRP ID	Age	20-Year ESAL	PREDICTED 1ST PERF. PERIOD					ESAL CUMM. UP TO SURVEY DATE				
			RL-A	RL-B	RL-C	RL-D	RL-E	RL-A	RL-B	RL-C	RL-D	RL-E
	years	million	years	years	years	years	years	million	million	million	million	million
1047	19.3	5.993	19	17	9	4	2	5.598	4.839	2.202	0.879	0.420
1047	20.4	5.993	19	17	9	4	2	5.598	4.839	2.202	0.879	0.420
1047	21.9	5.993	19	17	9	4	2	5.598	4.839	2.202	0.879	0.420
1050	4.7	0.651	NS	NS	NS	NS	NS					
1050	5.8	0.651	8	6	2	NS	NS	0.208	0.150	0.046		
1050	7.3	0.651	8	6	2	NS	NS	0.208	0.150	0.046		
1050	9.3	0.651	26	22	11	5	2	0.931	0.740	0.304	0.122	0.046
1060	4.1	1.822	40	40	40	40	23					2.200
1060	5.1	1.822	40	40	40	22	8				2.071	0.583
1060	7.4	1.822	40	40	40	22	8				2.071	0.583
1060	7.8	1.822	40	40	40	31	13				3.342	1.046
1060	8.1	1.822	40	40	40	31	13				3.342	1.046
1060	8.4	1.822	40	40	40	31	13				3.342	1.046
1060	8.7	1.822	40	40	40	31	13				3.342	1.046
1060	8.9	1.822	40	40	40	40	18					1.585
1060	9.1	1.822	40	40	40	40	18					1.585
1060	9.3	1.822	40	40	40	40	18					1.585
1068	2.9	1.666	7	4	NS	NS	NS	0.457	0.244			
1068	4.4	1.666	18	13	3	NS	NS	1.449	0.957	0.179		
1068	6.0	1.666	28	22	8	3	NS	2.643	1.894	0.533	0.179	
1068	6.6	1.666	28	22	8	3	NS	2.643	1.894	0.533	0.179	
1068	6.9	1.666	40	38	19	8	3		4.115	1.556	0.533	0.179
1068	7.1	1.666	28	22	8	3	NS	2.643	1.894	0.533	0.179	
1068	7.4	1.666	28	22	8	3	NS	2.643	1.894	0.533	0.179	
1068	7.6	1.666	28	22	8	3	NS	2.643	1.894	0.533	0.179	
1068	7.9	1.666	28	22	8	3	NS	2.643	1.894	0.533	0.179	
1068	8.1	1.666	18	13	3	NS	NS	1.449	0.957	0.179		
1077	8.8	4.165	9	7	2	NS	NS	1.531	1.142	0.292		
1077	9.9	4.165	9	7	2	NS	NS	1.531	1.142	0.292		
1077	11.3	4.165	9	7	2	NS	NS	1.531	1.142	0.292		
1077	12.0	4.165	2	1	NS	NS	NS	0.292	0.142			
1077	12.3	4.165	9	7	2	NS	NS	1.531	1.142	0.292		
1077	12.5	4.165	13	10	4	1	NS	2.391	1.735	0.611	0.142	
1077	12.8	4.165	13	10	4	1	NS	2.391	1.735	0.611	0.142	
1077	13.0	4.165	9	7	2	NS	NS	1.531	1.142	0.292		
1077	13.3	4.165	13	10	4	1	NS	2.391	1.735	0.611	0.142	
1077	13.5	4.165	9	7	2	NS	NS	1.531	1.142	0.292		
1094	13.6	0.243										
1094	14.7	0.243										
1094	16.4	0.243										
1094	18.0	0.243										
1096	9.0	1.126	40	40	40	40	23					1.360
1096	10.7	1.126	40	40	40	40	26					1.610
1096	11.7	1.126	40	40	40	40	26					1.610
1096	13.5	1.126	40	40	40	40	26					1.610

Table 3.20 Predicted ESAL Cumulative up to the Date of Survey (continued)

SHRP	Age	20-Year	PREDICTED 1ST PERF. PERIOD					ESAL CUMM. UP TO SURVEY DATE				
ID		ESAL	RL-A	RL-B	RL-C	RL-D	RL-E	RL-A	RL-B	RL-C	RL-D	RL-E
	years	million	years	years	years	years	years	million	million	million	million	million
1113	4.3	1.738										
1113	6.0	1.738										
1130	17.7	0.842	40	40	30	17	8			1.474	0.680	0.269
1130	19.6	0.842	40	40	30	17	9			1.474	0.680	0.309
1168	4.6	0.037										
1168	5.6	0.037										
1168	7.7	0.037										
1168	9.5	0.037										
1178	1.8	0.933	40	40	40	40	39					2.395
1178	3.7	0.933	40	40	40	40	40					
1178	4.9	0.933	40	40	40	40	40					
3579	2.8	1.792	5	3	NS	NS	NS	0.336	0.193			
3579	3.4	1.792	12	9	3	NS	NS	0.932	0.659	0.193		
3579	5.3	1.792	12	9	3	NS	NS	0.932	0.659	0.193		
3579	7.0	1.792	12	9	3	NS	NS	0.932	0.659	0.193		
3729	6.8	2.626	40	40	40	26	12				3.755	1.366
3729	7.9	2.626	40	40	40	26	12				3.755	1.366
3729	8.8	2.626	40	40	40	30	14				4.596	1.654
3729	10.2	2.626	40	40	40	30	14				4.596	1.654
3729	11.8	2.626	40	40	40	40	25					3.556
3739	7.9	2.777	18	15	8	4	2	2.416	1.909	0.889	0.407	0.194
3739	9.0	2.777	20	18	10	5	2	2.777	2.416	1.157	0.521	0.194
3739	9.9	2.777	20	18	10	5	2	2.777	2.416	1.157	0.521	0.194
3739	11.3	2.777	24	21	12	6	3	3.555	2.964	1.444	0.639	0.299
3739	11.6	2.777	24	21	12	6	3	3.555	2.964	1.444	0.639	0.299
3739	12.0	2.777	24	21	12	6	3	3.555	2.964	1.444	0.639	0.299
3739	12.2	2.777	22	19	10	5	2	3.157	2.594	1.157	0.521	0.194
3875	5.3	1.872										
9005	3.6	0.373	NS	NS	NS	NS	NS					
9005	4.6	0.373	31	24	8	2	NS	0.684	0.477	0.119	0.026	
9005	6.3	0.373	40	38	17	6	2		0.921	0.301	0.086	0.026
9005	8.1	0.373	40	40	40	25	12				0.505	0.194

Note:

RL stands for reliability level.

categories, which can lead to selection of a different treatment type even for a very small error in the prediction of PSI. In the above example, a PSI prediction model should not predict a PSI value of 3.75 or 2.75 in place of 3.25. That is, the error should not be such that a PSI at the middle of a range of PSI for a particular treatment type shifts to the middle of the adjacent ranges. The shifting of treatment type due to a small error of PSI values near the boundary can be expected to be compensated by similar movements in the reverse direction. Similarly, if performance models are used to optimize or prioritize pavement section selection, prediction should be accurate enough that the section, treatment category, and application time selected based on predicted performance do not significantly change the cost-effectiveness or economic return that would have been achieved if the actual performance was known. In the case of pavement design using performance models, the predicted performance values should be accurate enough that the life-cycle cost of the design for the same quality of service (including traffic and environmental condition) or the quality of service for the same life-cycle cost does not vary significantly from the design using actual performance values.

In this project, performance models were not evaluated by comparing the decisions made at network and project levels (such as needs estimate, thickness design, etc.) using the predicted and observed performances. The PMIS uses several other performance measures (i.e., transverse cracking) in addition to those selected for evaluation in this study to make decisions at network level. Moreover, the observed data points are insufficient to compute effectiveness values of treatments (area between the performance curves). Therefore, it was decided that the prediction models would be evaluated comparing the predicted and corresponding observed condition values.

A single criterion of difference between the predicted and observed value cannot evaluate prediction models. Evaluation needs to consider the following:

- **Faulty Data, Outlier** - Faulty data are generally due to recording errors during collection and errors in transferring data to the computer database. Analyses that include faulty data can lead to erroneous conclusions. Detection of faulty data is sometimes very difficult, especially when the relationships between the dependent variable and the independent variables are not known. Sometimes they can be detected as misfits in the general trend of observed data. For example, it is expected that distress increases with age of a pavement and does not decrease unless a M&R treatment is applied. If a particular distress observation shows less distress than that found in a previous observation, it may be faulty.

Some variation is expected among repeated observations irrespective of whether the data is collected manually or using automated equipment. For example, the LTPP database presents IRI data collected using a profilometer. It was found that even for the runs marked “good” there are some variations between each run. For example, 10 IRI values (m/km) from five test runs conducted on LTPP section 1047 on 10/29/90 between 11:44:52 hours and 12:36:20 hours are 2.052, 1.967, 2.017, 1.983, and 1.987 along the left wheel path and 2.139, 2.172, 2.161, 2.155, and 2.170 along the right wheel path. All of these runs are marked good. Out of several observations, there may be a few observations that vary dramatically from most of the data. These are often called outliers (13). Observations which are larger than the 75th percentile by more than three times the interquartile range (IQR, difference between the 75th and 25th percentile) or smaller than the 25th percentile by more than three times the IQR are generally called extreme outliers (13). If the differences are more than 1.5 times the IQR then they are commonly called mild outliers (13). Outliers have a very low probability of occurrence and probably should not be used for decision making in general applications. Outliers can be detected using statistical analysis and by visual examination of the data plot (13).

- **Special Effect** - Models often do not consider all factors that affect performance prediction. Therefore, a model may not accurately predict performance on some particular occasions due to the influence of those factors not considered. If the observed data shows a trend that may be due to some special factor while other data indicates the presence of that factor, then the presence of the special effect can be surmised. It is necessary to identify these special effects and develop separate performance models considering the special effects, if the existing performance models do not predict the performance with acceptable accuracy. The observed data showing special effects must be excluded from the general evaluation if development of separate performance models is under consideration to deal with this problem. This is because evaluation of a performance model using an observed data set containing special effects may lead to a conclusion significantly different from the same made from the evaluation without special effects in the observed data set.

- **Range of Independent Variable** - Empirical models are developed from observed data using regression techniques. Any such model is valid only within the limits of the observed data upon which it was developed. Regression models should not be extrapolated. For this reason, if a performance model is claimed to be valid for a certain range of an independent variable, then it is necessary to test the model with observed data spanning over that range.

  In addition, a performance model cannot be evaluated completely if the observed data only span a small portion of the valid range. Even if all the observed data over a small range of the entire prediction area point exactly on the prediction curve, the remaining portion of the prediction area remains unchecked. Figure 3.4 shows how partial data can cause ambiguity. The goodness of a model cannot be determined from a good match between the predicted values and observed values spanning only a small range of the entire prediction area. However, if the predictions compared to the observed values match poorly over a small range, it can generally be concluded that the model is not a good predictor.

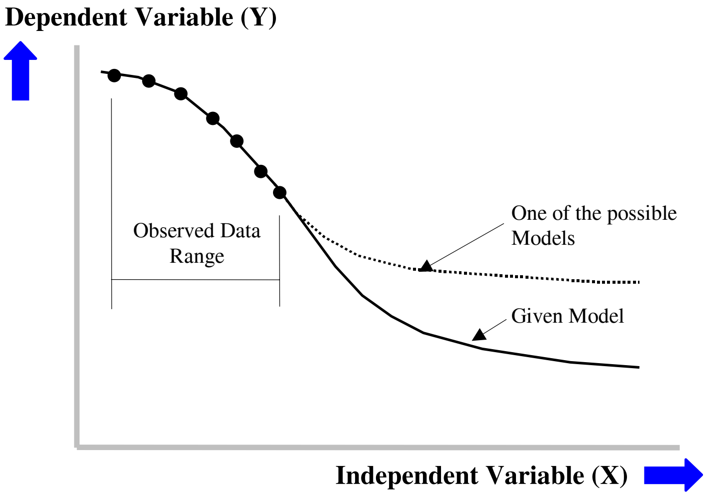


Figure 3.4 Ambiguity from Partial Data

- **Trend** - A lack of close prediction does not necessarily prove that the prediction equation is a poor model. The observed data can show a trend different from the prediction model which can be corrected by adjusting the model. A model needs adjustment if a definite different trend is revealed from the observed data. A trend is commonly determined by plotting the predicted and observed values and visually estimating the trend of one with respect to the other. The predicted data trends are easily understood because of their regularity (obtained from definite mathematical equations). Generally the prediction model is plotted as a line and the observed data are plotted as discrete points. The plot can show different trends as shown in figure 3.5 and described as follows:

  - Parallel Trend - when the observed data trend is parallel to the predicted data trend;
  - Crossing Trend - when the observed data trend is steeper than the predicted data trend, or vice-versa; and
  - Scatter - when the observed data are scattered around the predicted data trend and no definite trend is revealed.

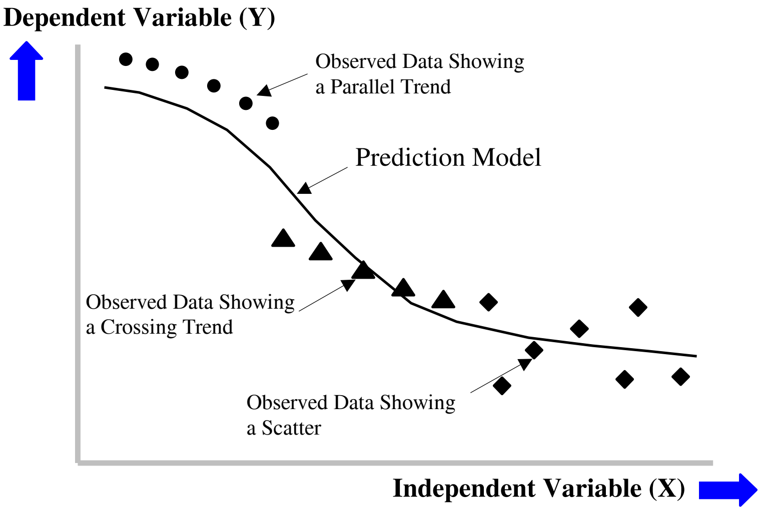


Figure 3.5 Trends of Observed Data

- **Accuracy** - Accuracy of prediction is one of the most vital attributes of a prediction model. Accuracy indicates the closeness of the predicted value to the true value. The R-square value is one of the commonly used statistics to describe the "goodness of fit" or how much of the total variation is explained by the regression model (4, 14). The R-square statistic can have a value between zero and one (inclusive), where a value of one represents a model without any error (i.e., all points lie exactly on the regression line). On the other hand, an R-square value of zero implies that there is no correlation among the points and that the model does not explain the variation of the observed data. Since the value of the R-square statistic changes due to addition or deletion of independent parameters, a higher R-square value does not necessarily imply a better model. Therefore, an R-square value must be carefully used as an evaluation tool.

  The standard error of estimate (SEE), also called the root mean square error (RMSE), is often used to describe the accuracy of a prediction model (4, 14). The SEE statistic (analogous to standard deviation) describes the amount of scatter of the observed values about the mean predicted value. A lower value of SEE indicates a more accurate model.

Some authors prefer to use a confidence interval (interval of prediction for a specific level of confidence) as shown in figure 3.6 and describe the accuracy of a model using the width of the interval. There are two types of confidence intervals. One is for predicting a single value of the dependent variable for particular values of the independent variables and is called the prediction interval. The other one is for predicting the average value of the dependent variable corresponding to particular values of the independent variables. An 80 percent prediction interval is a region where 80 percent of the observed values is expected to fall. A 90 percent prediction interval is wider than an 80 percent prediction interval. A narrower region indicates a more accurate prediction model.

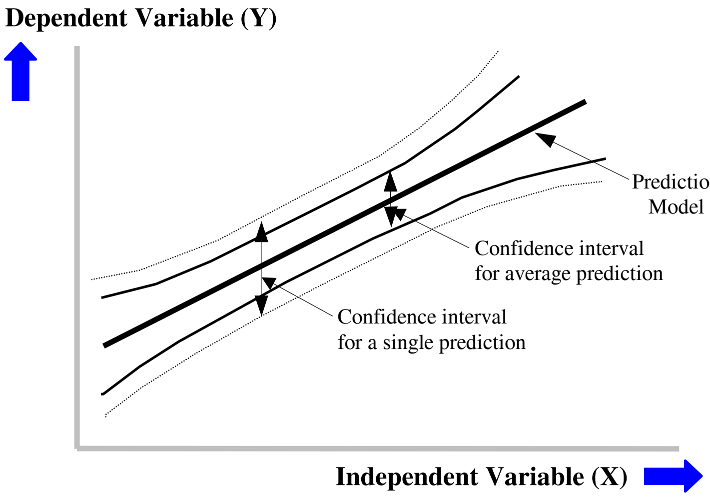


Figure 3.6 Confidence Intervals of Prediction Model

The R-square, SEE, and confidence limits are calculated during development of a regression model for a sample of data points. A prediction model is accepted or rejected based on the values of these statistics. For the evaluation of an existing performance prediction model, the original values of these statistics are required to check how their values are changing when the same prediction model is compared with another set of data points (data used for testing). The original regression statistics (R^2, SEE, etc.) of the PMIS and FPS-19 models are not available, and for that reason they cannot be checked.

The average of differences (in percentage) between the observed values and the corresponding predicted values from a sufficiently large number of observations can be used as a surrogate for accuracy when the true values are not known. However, since variation is always present, the average percent difference does not give an adequate description of the predictions compared to the observed values. It is necessary to determine the standard deviation of percent differences to depict the variation. For example, from 100 pairs of observed and predicted values, 100 values of percent differences between the predicted and corresponding observed values can be computed and from those values an average value can be computed. Although this average value represents the central tendency of percent difference values, it fails to give an idea about the variation of percent difference values, which may or may not vary significantly. Therefore, the standard deviation of percent differences needs to be computed along with the mean to describe the accuracy of a performance model.

- **Reliability** - Reliability considers the variability and looks into the objective of modeling. AASHTO defines the reliability of a pavement design-performance process as “the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period” (15). Thus, a reliability of 95 percent indicates that there is a 95 percent probability of satisfactory service from the design/system (or a 5 percent chance of failure) within the design period. FPS-19 provides options for design with any of five reliability levels (80 to 99.9 percent). Therefore, for pavements designed with an 80 percent reliability, at most 20 percent of cases can fail within the design period. FPS-19 uses serviceability as the failure criteria. This means that if the terminal serviceability falls below a predefined value within the design period, then the pavement is considered failed. Hence, a maximum of 20 percent of pavements designed at an 80 percent reliability level can be expected to develop terminal SI values less than that predicted by the serviceability prediction model of FPS-19 within the design period. If the observed terminal SI is less than the predicted terminal SI in 30 percent of the cases, then it can be said that the reliability of such designs is 70 percent and not 80 percent. Therefore, it is necessary to check the reliability of a design as promised by a design model with the estimated reliability. Reliability is generally associated with a system or design. Statistically, reliability is not a property of performance prediction models.

The reliability of a design can be estimated from the chance of success or failure. The success or failure of design is generally determined based on the values of one or more performance measures. Therefore, the performance prediction models used for pavement designs have some relationship with reliability values of the designs. If a pavement is designed using a fatigue cracking prediction model, the probability of success of a design (reliability) can be computed as the percentage of cases with the observed fatigue cracking less than the predicted fatigue cracking (which governs success of a design). The number of observations must be sufficiently large. For other performance measures, if the chance of failure decreases with an increase in the value of the performance measure (i.e., ride quality, ESAL), then the percentage of cases with the observed value more than the predicted value gives the chance of success. For example, if a pavement is designed using a ride quality prediction model, then the reliability of this design can be estimated as the percentage of cases with the observed ride quality greater than the predicted ride quality (since better ride quality indicates a smaller chance of failure). Although a more reliable model is appealing, it leads to the design of a stronger pavement and requires more funds. The user delay costs associated with construction and rehabilitation of high-trafficked roads, such as freeways, are often more than low-trafficked roads, such as Farm to Market (FM) roads. This is one of the reasons why higher reliabilities are used when designing pavements on important roads. But it may not be economical if higher reliability is provided for less important roads. In the case of the selected pavement sections, five out of 15 sections are rural minor arterials and rural minor collectors. Thus a higher reliability would not be desirable for all of the LTPP sections. On the other hand, a reliability of less than 50 percent should not be allowed because at this reliability level there are more chances of failure than survival.

- **Other Criterion for Statistical Analysis** - One of several ways to check a performance model is through statistical hypothesis testing. Hypothesis testing is discussed later in this chapter. For every statistical analysis there may be one or more assumptions regarding the sample and population characteristics. Since the probability of error (Type I or II) in rejecting a hypothesis is the deciding factor and this is computed assuming some probability distribution, it is essential that the data follow that probability distribution, at least approximately. An approximately normal probability distribution (normality), independence of data, and adequate sample size are some of the requirements (13).

Hypothesis Testing

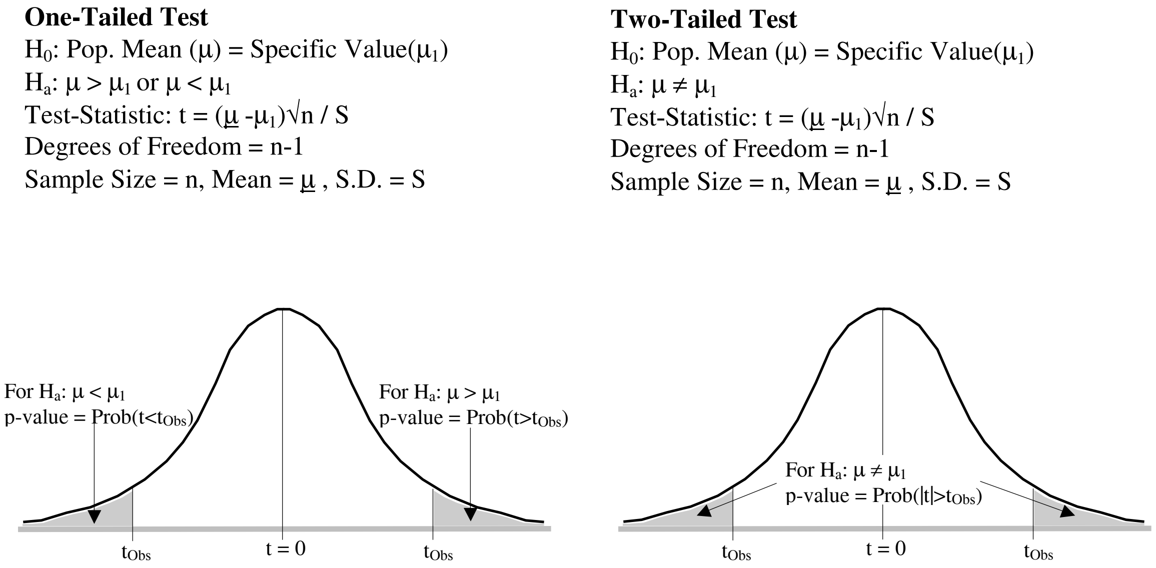
Hypothesis testing is a statistical procedure used to make an inference about a population parameter from a sample (subset of population). The inferences are generally about the population parameters taking specific values. In such tests, two hypotheses are made: 1) the research or alternate hypothesis (H_a) and 2) the null hypothesis (H_0). A research hypothesis is about some findings of the research, i.e., “Tylenol® works better than Advil® in relieving headaches.” The research hypothesis is verified by contradicting/rejecting the null hypothesis. The null hypothesis in the earlier example can be stated “Tylenol and Advil have the same power of relieving headaches.” Rejection or acceptance (rather, not rejection) of a null hypothesis is based on the observed value of a test statistic and the level of significance (13).

The selection of test statistic, such as student-t, F, χ^2, etc., and subsequent computation of the observed value of the test statistic depends on the parameter to be tested (i.e., mean, variance, etc.). As with any two-way decision process, an error can be made by falsely rejecting the null hypothesis or by falsely accepting the null hypothesis. A Type I error is committed if the null hypothesis is rejected when it is true. The probability of a Type I error is denoted by α. A Type II error is made when the null hypothesis is not rejected when it is false and the research hypothesis is true. The probability of a Type II error is denoted by β. Although it is desirable to test a hypothesis by simultaneously minimizing α and β, this is not possible as α and β are inversely related. If α increases, β decreases. Generally testing is done based on a value of α (i.e., 0.01, 0.05, 0.10) specified by the experimenter (13).

A **p**-value, or a level of significance, is the probability that the test statistic will be more than the observed value of the test statistic. Smaller **p**-values indicate more sample evidence against the null hypothesis. If the **p**-value is less than the specified value of α, the null hypothesis can be rejected since the probability of a Type I error is less than the value of α. The **p**-value is computed from the probability distribution of the test statistic, the degrees of freedom, and the number of tails. The number of tails refers to whether the test is one sided (one-tailed) when the alternate hypothesis sets the parameter more than or less than a specified value or two sided (two-tailed) when the alternate hypothesis sets the parameter not equal to a specified value. Figure 3.7 shows typical one-tailed and two-tailed tests (13).

Since the technique of hypothesis testing was used in the evaluation process, a brief description of hypothesis testing is provided. The details of hypothesis testing are available in any standard textbook on statistical methods (13).

In an observed versus predicted data plot, the line of equality (for predicted values equal to observed values) passes through the origin and makes an angle of 45 degrees with the x-axis. The regression line (least-square) obtained from the observed (x) and predicted (y) data set is expected to have a zero intercept (B_0=0) and a 45° slope (B_1=1) to be equivalent to the line of equality. The regression line obtained from the least-square method presents the



One-Tailed Test
H_0: Pop. Mean (μ) = Specific Value(μ_1)
H_a: $\mu > \mu_1$ or $\mu < \mu_1$
Test-Statistic: $t = (\underline{\mu} - \mu_1)\sqrt{n} / S$
Degrees of Freedom = n-1
Sample Size = n, Mean = $\underline{\mu}$, S.D. = S

Two-Tailed Test
H_0: Pop. Mean (μ) = Specific Value(μ_1)
H_a: $\mu \neq \mu_1$
Test-Statistic: $t = (\underline{\mu} - \mu_1)\sqrt{n} / S$
Degrees of Freedom = n-1
Sample Size = n, Mean = $\underline{\mu}$, S.D. = S

Figure 3.7 Level of Significance for Typical One- and Two-Tailed Tests

expected (average) relationship and may be different from the line of equality as shown in figure 3.8. However, from the standard errors for the estimates of intercept and slope and considering a normal distribution of the residuals, a 100 (1-α) percent confidence interval for the true values of the intercept and slope can be constructed. If the required intercept and slope fall beyond the confidence interval then it can be said that predictions do not match with the observed data. In terms of the probability of Type I error (α), it can be said that the null hypothesis can be rejected if the p-value is less than α.

However, the null hypothesis, “predicted values are the same as observed values,” which indicates goodness of a prediction model, can be rejected if any one of the two null hypotheses: 1) “ intercept is zero” and 2) “slope is one” is rejected.

A correlation coefficient (r) provides a measure of the strength of a linear relationship between two variables. The value of **r** lies between -1 and +1. A value of **r** at zero indicates that there is no linear relationship between the variables. Therefore, a null hypothesis, “correlation coefficient is zero” was considered and tested against the alternate hypothesis, “correlation coefficient is not zero.” A rejection of the null hypothesis implies that a linear relationship can be expected between the observed and predicted values.

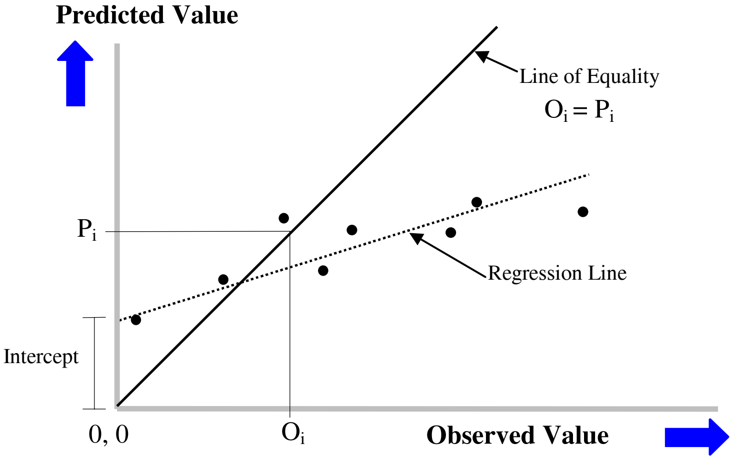


Figure 3.8 Line of Equality

Rejection of both the null hypotheses, “predicted values are the same as observed values” and “correlation coefficient is zero” implies that although the predicted values are not the same as the observed values, there is some weak relationship between the values predicted by the performance model and the values observed. It is also possible to find some performance models for which the former hypothesis can be rejected, but the latter one cannot be rejected. This implies that the predicted values are not the same as the observed values, and they have no relation with the observed values. These performance models have the worst predictive capabilities. Good prediction models are those for which the null hypothesis, “predicted values are the same as observed values” cannot be rejected, but the null hypothesis, “correlation coefficient is zero” can be rejected.

In an observed verses predicted data plot, if the data points are distributed evenly on either side of the line of equality, the least-square line for this data set may coincide with the line of equality irrespective of how far they are from the line of equality. The R-square statistic gives an indication of how well the regression line fits the data set. An R-square value of around 0.7-0.8 is often considered a good fit for pavement performance models.

The necessary details for the testing of the null hypotheses considered for the evaluation of performance models are given in table 3.21.

All null hypotheses were tested using **t**-statistics. The observed value of each **t**-statistic was computed from the estimated value of the parameter tested (such as slope), the

Table 3.21 Definitions of Hypotheses Tested and Related Equations

Null hypothesis (H_0):	Intercept (B_0) = 0	Slope (B_1) = 1	Corr. Coeff (r) = 0
Alternate hypothesis (H_a):	$B_0 \neq 0$	$B_1 \neq 1$	$r \neq 0$
Test statistic:	$t_{Obs} = (B_0 - 0) / SE_{B0}$ $B_0 = \bar{y} - B_1 \bar{x}$ $SE_{B0} = \sqrt{\frac{\sum x^2 \sum (y-\bar{y})^2}{n(n-2)\sum (x-\bar{x})^2}}$	$t_{Obs} = (B_1 - 1) / SE_{B1}$ $B_1 = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sum (x-\bar{x})^2}$ $SE_{B1} = \sqrt{\frac{\sum (y-\bar{y})^2}{(n-2)\sum (x-\bar{x})^2}}$	$t_{Obs} = (r - 0) / SE_r$ $r = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2}\sqrt{\sum (y-\bar{y})^2}}$ $SE_r = \sqrt{\frac{(1-r^2)}{(n-2)}}$
Degrees of freedom (df):	df = n-2	df = n-2	df = n-2
Prob ($\lvert t \rvert > t_{Obs}$) = p-value:	TDIST(t_{Obs}, n-2, 2)	TDIST(t_{Obs}, n-2, 2)	TDIST(t_{Obs}, n-2, 2)
Maximum acceptable Probability of Type I Error (α):	0.05	0.05	0.05
95% Confidence Interval:	$B_0 \pm t_{0.05,\,df}\, SE_{B0}$	$B_1 \pm t_{0.05,\,df}\, SE_{B1}$	Not Computed

hypothesized true value of that parameter (such as one), and the standard error for that parameter. The estimated values of the test parameters were computed from the observed (x) and predicted (y) data pairs using the equations given in table 3.21. The standard errors for the test parameters (such as SE_{B1}) were computed from the observed and predicted data pairs and the number of data pairs (n) as shown in table 3.21. The **p**-values were obtained from the observed values of **t**-statistics, degrees of freedom, and the number tails utilizing the function, TDIST, available in Microsoft Excel® computer software. In all hypotheses, tests were two-tailed. A 5 percent level of significance was used as a rejection or acceptance criterion.

Evaluation Strategy

The evaluation strategy was based on the objective of the research, specific items to be evaluated, and available data. These are summarized in the following:

- The objective of this project was to determine if the performance models used by TxDOT at network- and project-level pavement management are working satisfactorily or some/all of them need improvement.
- Items to be evaluated were the following performance models, specifically meant for the original flexible pavements with granular base:

    - PMIS Ride Quality Model,
    - PMIS Alligator Cracking Model,
    - PMIS Shallow Rutting Model,
    - PMIS Deep Rutting Model, and
    - FPS-19 Serviceability Model.

- Available data for testing the models is that included in the LTPP database for Texas sections.

PMIS Models

All PMIS performance models use a sigmoidal form with pavement age as the sole independent variable. These models use six parameters (α, β, ρ, χ, ε, σ) whose values are dependent on pavement type, treatment type, traffic class, subgrade type, environmental condition, and 20-year projected ESAL. Hence, a performance model (i.e., the shallow rutting model) actually refers to a family of performance models (that predict shallow rutting). Each member of a family has at least one different parameter value than any other member. With reference to the original pavements with granular bases, each member of a model family is for one of the following:

- four pavement types (ACP04, ACP05,ACP06, and ACP10);
- one treatment type (Hrhb);
- three traffic classes (low, medium, and high) (only applicable to ride quality); and
- five subgrade classes (very good, good, fair, poor, and very poor).

In terms of the values of the model parameters, the possible values/ranges of the parameters related to an original pavement with a granular base are given in table 3.22. In table 3.22, it may be observed that for a particular value of Chi (or 20-year ESAL), the number of members in a family varies between 20 (1 x 1 x 4 x 1 x 5) and 5 (1 x 1 x 1 x 1 x 5). Although 20-year ESALs can have any value, the Chi values and performance do not change with 20-year ESAL beyond the ranges given in table 3.23. However, the absence of the following data items was identified in the available database:

- ACP10 (surface treatment over base) type of pavement;
- subgrade class very good and fair for the pavement type ACP04, very good, good, and very poor for ACP05, and good and very poor for ACP06 and;
- 20-year ESAL more than 5.933 million ESAL for ACP04, more than 4.165 million ESAL for ACP05, and more than 2.777 million ESAL for ACP06.

Table 3.22 The Possible Values/Ranges of the Model Parameters

Parameter	Ride Quality	Alligator Cracking	Shallow Rutting	Deep Rutting
Alpha	1.0	100.0	100.0	100.0
Beta	2.0	1.69	2.55	1.00
Rho	8.1, 8.5, 10.4	8.1, 8.4, 12.1, 11.3	5.8, 6.6, 8.9, 7.1	13.45
Chi	1.12-0.94	1.3-0.7	1.18-0.83	1.18-0.83
Epsilon	1.0	1.0	1.0	1.0
Sigma	1.00, 1.04, 1.08, 1.14, 1.19	1.00, 1.21, 1.42, 1.61, 1.80	1.00, 1.21, 1.42, 1.61, 1.80	1.00, 1.21, 1.42, 1.61, 1.80

Table 3.23 Twenty-Year Projected ESAL Range Related to Variation of Chi Factor

Values in Million ESAL

Pavement Type	Ride Quality Model	Alligator Cracking Model	Shallow Rutting Model	Deep Rutting Model
ACP 04	1.964-22.015	2.386-22.481	2.234-23.081	2.234-23.081
ACP 05	0.811-10.962	1.001-11.293	0.927-11.483	0.927-11.483
ACP 06	0.307-4.150	0.379-4.309	0.351-4.376	0.351-4.376
ACP 10	0.100-1.521	0.124-1.607	0.115-1.635	0.115-1.635

The PMIS performance models can be used to predict performance for up to 40 years. So for complete evaluation of these models, performance data is needed spanning over a 40-year period. Figure 3.9 presents histograms showing the frequency (number) of observations for ride quality, alligator cracking, and rutting at different pavement ages. These histograms show that the maximum number of ride data (22 percent) and alligator cracking data (29 percent) fall in the pavement age group of 8-10 years. The maximum number of rutting data (35 percent) fall in the age group of 4-6 years.

Thus considering the available data, which is inadequate for complete evaluation of the selected performance models, the following steps were performed:

- **Data Censorship** - In this step faulty data, outliers, and data with special effects were identified and excluded from further use. Faulty data and outliers were detected by visual inspection. Special effects were identified from trends of the observed performance data, inventory, environmental data, and traffic data.
- **Trend Analysis** - Trends of the observed performances with respect to the predicted performances were analyzed separately for each pavement section by visual inspection.
- **Hypothesis Testing** - Three null hypotheses: 1) “intercept is zero,” 2) “slope is one” and 3) “correlation coefficient is zero” were tested separately for each section having a minimum of three observed data points and wherever the data trend allowed. A 5 percent level of significance was used as a rejection criterion. Hypotheses were also tested for each pavement category and each selected prediction model family as a

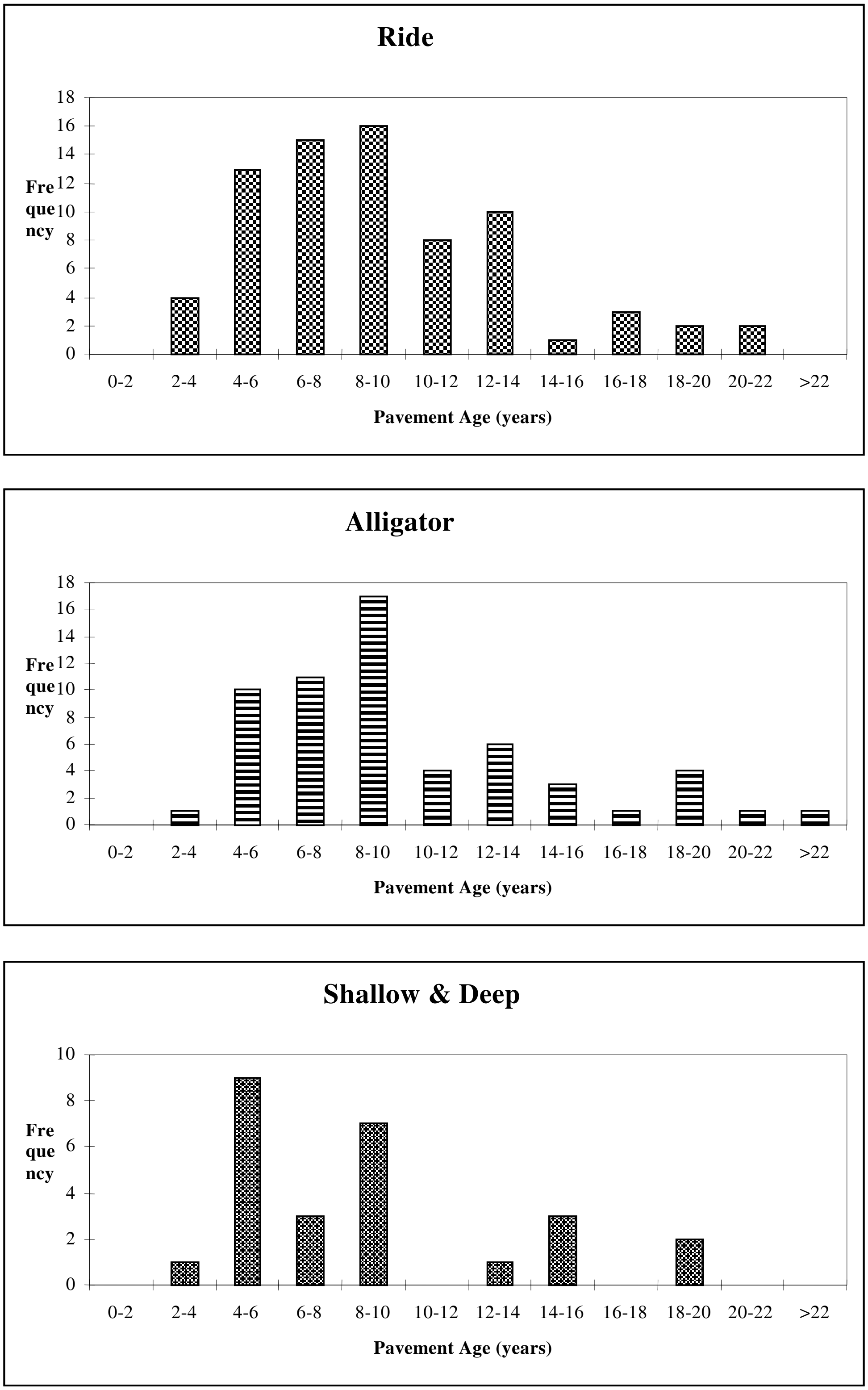


Figure 3.9 Histograms of Pavement Ages for Ride Quality, Alligator Cracking, and Rutting

whole. Due to the lack of rutting data, hypotheses testing on shallow and deep rutting models could not be performed for each section separately.

- **Accuracy Assessment** - Since the true values of the performance measures were not known, accuracy could not be determined. However, average percent differences were computed for each section from the average of percent differences in all the observations. The percent differences were computed by dividing the differences between the observed and predicted values by the predicted values and then multiplying them by 100. The standard deviation of percent difference was also computed to evaluate the variation. The mean and standard deviation of percent difference for ride quality and alligator cracking models were computed for optimistic, pessimistic, and average scenarios.

  For ride quality models, the maximum and minimum observed values at the same age of the pavement were used. Percent difference under each scenario was computed as:

  - minimum of PMAX and PMIN for the optimistic scenario,
  - maximum of PMAX and PMIN for the pessimistic scenario, and
  - PAVG for the average scenario.

  PMAX is the percent difference between the observed maximum and predicted value, PMIN is the percent difference between the observed minimum and predicted value, and PAVG is the percent difference between the observed average and predicted value. The optimistic and pessimistic scenarios represent the minimum percent difference (favoring models) and the maximum percent difference (disfavoring models), respectively.

  The same methods were used to evaluate the alligator cracking model. However, tests replaced the maximum and minimum observed values with the upper and lower limits of the 95 percent confidence interval. The upper and lower limits of the 95 percent confidence interval were computed assuming each observed value as the average cracking corresponding to a pavement age and considering a coefficient of variation (standard deviation divided by the mean) of 30 percent. This value for the coefficient of variation was assumed based on the findings of a study on the assessment of variability in LTPP manual distress data (10). The study reports a coefficient of variation (COV) in the range of 33 to 40 percent for total distress data (all severity classes combined) on fatigue cracking and longitudinal cracking in the wheel path collected by single raters. In the case of the specific data extracted from the LTPP database, two raters jointly conducted 17 out of 159. Hence, a COV of 30 percent was assumed.

Due to the non-availability of variation (among several measurements at the same location and not along the length) of rutting data collected in the LTPP study, researchers could not perform assessment of percent difference for different scenarios.

- **Reliability Assessment** - The PMIS performance models are not used for pavement design, and so the reliability values of designs using these models do not arise.
- **Percentage of Over-prediction** - The PMIS models are expected to predict an average value. In other words for a large number of observations, the percentage of under-prediction (number of observed values greater than the predicted values) should be the same as the percentage of over-prediction (number of observed values less than the predicted values). With respect to this attribute, the PMIS models are similar to the design models that provide 50 percent reliability of designs. Thus, it was necessary to check if the PMIS models are over-predicting or under-predicting.

The percentages of over-prediction and under-prediction were estimated by finding the percentage of observations with the observed values less than and more than the predicted values, respectively. The percentage values of over-prediction for the optimistic, pessimistic, and average scenarios were computed by considering, respectively, the minimum, the maximum, and the average observed values. The percentage values of under-prediction for the optimistic, pessimistic, and average scenarios were computed by considering, respectively, the maximum, the minimum, and the average observed values. For the alligator cracking model, the upper and lower limits of the 95 percent confidence interval were considered, respectively, for the pessimistic and optimistic scenarios. Only the average values could be estimated for the shallow and deep rutting models.

FPS-19

For FPS-19, complete evaluation requires evaluation of the mechanistic model that calculates the surface curvature index (SCI) as well as evaluation of the serviceability model that calculates the allowable ESALs. Although the observed surface curvature index could be computed from the LTPP FWD data, the values of predicted SCI were not known. Currently, FPS-19 does not provide the value of SCI that is used in the serviceability model. FPS-19 provides a performance period based on reliability levels from **A** (80 percent) to **E** (99.9 percent). Therefore, it was decided that FPS-19 would be evaluated using the predicted ESALs (back-calculated from predicted first performance period) at each reliability level and the observed ESALs. The following steps were used in the evaluation of FPS-19:

- Data Censorship - This was the same as that done for the PMIS ride quality model.
- Hypotheses Testing - This was the same as that done for the PMIS ride quality model. However, for FPS-19, tests were performed for each reliability level, **A** through **E**.
- Accuracy Assessment - This was the same as that done for the PMIS ride quality model except that the average percent difference was not computed for each pavement type. The average and standard deviation of percent differences between the observed and predicted ESALs for each reliability level, **A** through **E**, were computed for all pavement types combined.
- Reliability Assessment - Reliability of design using FPS-19 was estimated by computing the percentage of observations with the observed ESALs greater than or equal to the predicted ESALs. The estimated reliability values were compared with the reliability levels of the design option. The reliability values for the optimistic, pessimistic, and average scenarios were computed by considering, respectively, the maximum, minimum, and average observed values.

Analysis and Inference

PMIS Ride Quality Model

Data Censorship - The plots of the observed and predicted data versus pavement age for each section are presented in Figures D.1 through D.16 of Appendix D. The following ride data were detected by visual examination and excluded from further analysis:

- Data for section 1047 at age 23.4 years were detected faulty as shown in Figure D.1.
- All data for section 1178 were considered a special case of swelling soil on the basis of subgrade soil characteristics, roughness data, and expert opinion (12).

Trend Analysis - Figures D.1 to D.16 of Appendix D, showing the predicted and observed ride quality at different ages of pavement, were used to determine trends visually. Table 3.24 shows the results of the trend analysis.

It may be observed that four ACP04 sections (1060, 1068, 1096, 3729) are showing crossing trends, and one ACP04 section (1047) is showing a parallel trend. For the pavement type ACP05, one section (1077) is showing a crossing trend and the other one (1130) is showing a parallel trend. Similarly for the pavement type ACP06, two sections (1094, 3739) are showing crossing trends while five sections (1050, 1113, 1168, 3579, 9005) are showing parallel trends. Since the trends are not consistent (i.e., not the same for all sections of a particular pavement type), the results from these analyses cannot be utilized to improve the models. However, it can be inferred that the trends of the predicted values and the observed values are distinctly different for all the LTPP sections except section 3875, for which the trend of the observed values could not be analyzed due to the lack of data.

Hypothesis Tests - Table E.1 of Appendix E presents the hypotheses tests conducted for each section. Out of 15 sections, tests could not be performed on three sections. The null hypotheses, “intercept is zero” and “slope is one” can be rejected for only one section (9005). The null hypothesis, “correlation coefficient is zero” can be rejected for four sections (1050, 1168, 3729, and 3739). Therefore, for section 9005 it can be inferred that the performance model is not predicting the ride quality values observed at this LTPP site and there is no

Table 3.24 Trends of Observed Ride Data

Section	Pavement Type	Trend
1047	ACP04	Parallel Trend above Predicted
1050	ACP06	Parallel Trend below Predicted
1060	ACP04	Crossing Trend Flatter than Predicted
1068	ACP04	Crossing Trend Flatter than Predicted
1077	ACP05	Crossing Trend Flatter than Predicted
1094	ACP06	Crossing Trend Flatter than Predicted
1096	ACP04	Crossing Trend Flatter than Predicted
1113	ACP06	Parallel Trend below Predicted
1130	ACP05	Parallel Trend below Predicted
1168	ACP06	Parallel Trend below Predicted
3579	ACP06	Parallel Trend below Predicted
3729	ACP04	Crossing Trend Flatter than Predicted
3739	ACP06	Crossing Trend Flatter than Predicted
3875	ACP06	Single observation
9005	ACP06	Parallel Trend below Predicted

linear relationship between the predicted and observed values. For the seven sections (1047, 1060, 1068, 1077, 1094, 1096, 3579), it can be inferred that although it cannot be denied that the performance models are predicting the ride quality values observed at these LTPP sites, there are no linear relationships between the predicted and observed values. It can also be inferred that models for four sections (1050, 1168, 3729, 3739) are predicting the ride quality values observed at these LTPP sites, and there are linear relationships between the predicted and the observed values. However, due to the small sample size, the results from section-wise hypotheses tests cannot be considered representative.

The same tests were performed for each type of pavement and ride quality model as a whole. Tables 3.25 through 3.28 present the hypothesis test parameters and plots of the observed versus predicted data, respectively, for ACP04, ACP05, ACP06, and ride quality model as a whole. The null hypotheses, “intercept is zero” and “slope is one ” cannot be

Table 3.25 Hypotheses Tests on Ride Quality Model for ACP04

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	-0.732	1.207	Correlation coeff.	0.741
Standard Error	0.747	0.200	t-statistic	6.045
t-statistic	-0.980	1.037	Degrees of freedom	30
Degrees of freedom	30	30	p-value (Prob>|r|)	0.000
p-value (Prob>|t|)	0.335	0.308	Reject H_0?	Can Reject
Upper 95%	0.793	1.615	Difference: Mean	0.366
Lower 95%	-2.258	0.799	Std. Deviation	0.312
Reject H_0?	Can't Reject	Can't Reject	Maximum	1.082
Regression Statistics:	R-square	0.5491	Minimum	0.020
	Root MSE	0.4837	No. of Observations	32

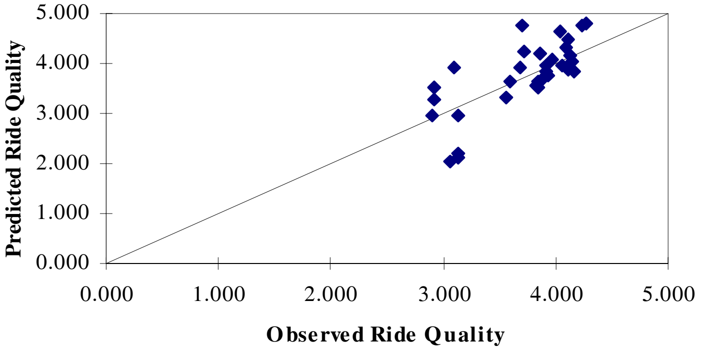


Table 3.26 Hypotheses Tests on Ride Quality Model for ACP05

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	1.751	0.330	Correlation coeff.	0.715
Standard Error	0.388	0.102	t-statistic	3.237
t-statistic	4.511	-6.577	Degrees of freedom	10
Degrees of freedom	10	10	p-value (Prob>|r|)	0.009
p-value (Prob>|t|)	0.001	0.000	Reject H_0?	Can Reject
Upper 95%	2.616	0.557	Difference: Mean	0.915
Lower 95%	0.886	0.103	Std. Deviation	0.332
Reject H_0?	Can Reject	Can Reject	Maximum	1.256
Regression Statistics:	R-square	0.5116	Minimum	0.360
	Root MSE	0.2976	No. of Observations	12

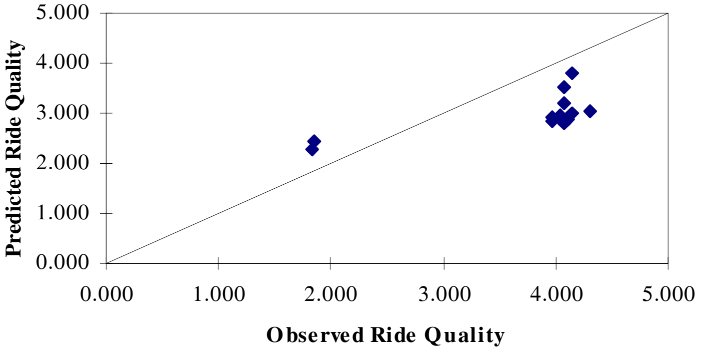


Table 3.27 Hypotheses Tests on Ride Quality Model for ACP06

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	3.087	0.306	Correlation coeff.	0.310
Standard Error	0.689	0.177	t-statistic	1.727
t-statistic	4.478	-3.908	Degrees of freedom	28
Degrees of freedom	28	28	p-value (Prob>|r|)	0.095
p-value (Prob>|t|)	0.000	0.001	Reject H_0?	Can't Reject
Upper 95%	4.499	0.670	Difference: Mean	0.765
Lower 95%	1.675	-0.057	Std. Deviation	0.334
Reject H_0?	Can Reject	Can Reject	Maximum	1.509
Regression Statistics:	R-square	0.0963	Minimum	0.099
	Root MSE	0.5954	No. of Observations	30

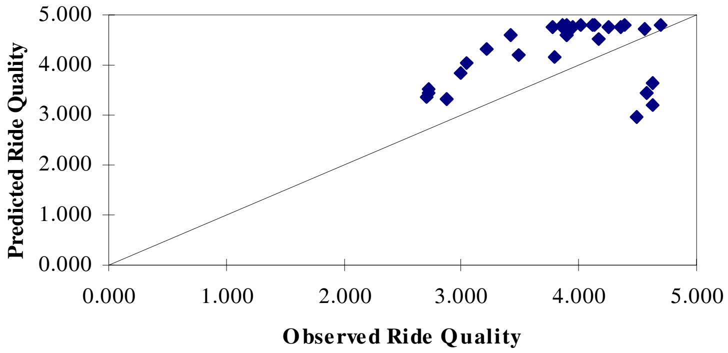
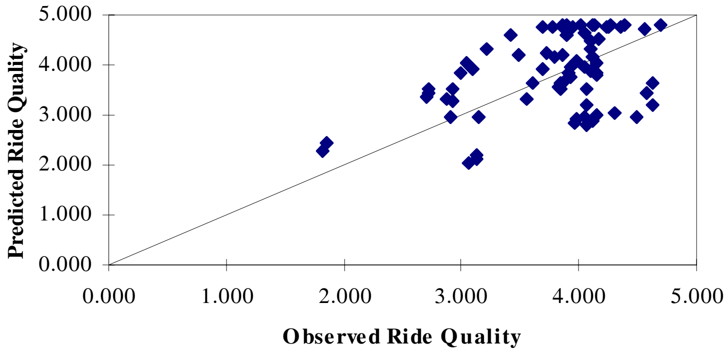


Table 3.28 Hypotheses Tests on Ride Quality Model as a Family

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	1.670	0.575	Correlation coeff.	0.447
Standard Error	0.517	0.136	t-statistic	4.236
t-statistic	3.230	-3.134	Degrees of freedom	72
Degrees of freedom	72	72	p-value (Prob>|r|)	0.000
p-value (Prob>|t|)	0.002	0.002	Reject H_0?	Can Reject
Upper 95%	2.701	0.845	Difference: Mean	0.617
Lower 95%	0.640	0.304	Std. Deviation	0.392
Reject H_0?	Can Reject	Can Reject	Maximum	1.509
Regression Statistics:	R-square	0.1995	Minimum	0.020
	Root MSE	0.6906	No. of Observations	74



rejected for only pavement type ACP04. The null hypothesis, “correlation coefficient is zero” cannot be rejected for only pavement type ACP06. All null hypotheses can be rejected for the ride quality model as a whole. From the test results it can be inferred that the performance model for pavement type ACP04 is predicting the ride quality values observed at five LTPP sections, and there is a linear relationship between the predicted and observed values. The performance model for pavement type ACP06 is not predicting the ride quality values observed at seven LTPP sites, and there is no linear relationship between the predicted and the observed values. It can also be inferred that the ride quality model as a family (and also the model for ACP05 separately) is not predicting the ride quality values observed at the 15 LTPP sites, although some linear relationship between the predicted and observed values cannot be denied.

Percent Difference - Table 3.29 presents percent differences for each pavement type and the ride quality model as a whole. It also gives the percent differences in optimistic, average, and pessimistic scenarios. It may be seen that the performance model for pavement type ACP04 is predicting better than the others with a mean percent difference of 11 percent and standard deviation of 13 percent difference in the average scenario. The ride quality model for pavement type ACP05 is predicting the worst with a mean percent difference of 26 percent and standard deviation of 12 percent difference even in the optimistic scenario. The mean and standard deviation of percent differences for the ride quality model family as a whole are 18 percent and 14 percent, respectively, in the average scenario.

Analyses of the ride quality models as a family show that the average difference between the observed and predicted ride score of 0.6 is more than the ranges used to define the level of service given in table 1.6 of reference 1. This implies that with this accuracy of prediction, the level of service cannot be determined properly. For example, the “tolerable” level of service for a high-trafficked road is defined by the ride score in the range 2.6-3.0. A 0.6 difference would allow the observed level of service to be “intolerable” or “acceptable” even when the predicted ride score is at the middle of the “tolerable” range.

Table 3.29 Percent Difference for Ride Quality Models

Pavement Type	Item	Optimistic Scenario	Average Scenario	Pessimistic Scenario
ACP04	Number of Prediction	32	32	32
	Percentage of Prediction	100	100	100
	Mean % Difference	7.9	11.1	15.8
	S. D. % Difference	10.7	12.7	14.3
ACP05	Number of Prediction	12	12	12
	Percentage of Prediction	100	100	100
	Mean % Difference	26.3	31.3	36.1
	S. D. % Difference	12.1	11.6	11.9
ACP06	Number of Prediction	30	30	30
	Percentage of Prediction	100	100	100
	Mean % Difference	14.6	18.8	22.8
	S. D. % Difference	10.4	10.5	11.1
Family	Number of Prediction	74	74	74
	Percentage of Prediction	100	100	100
	Mean % Difference	13.6	17.5	21.9
	S. D. % Difference	12.4	13.5	14.4

Percentage of Over-prediction - Table 3.30 presents the percentage values of over- and under-prediction for each pavement type as well as for the ride quality model as a family. It shows that the ride quality model for pavement type ACP06 is over-predicting in 87 percent of observations (under-predicting in 13 percent of observations) in all scenarios. In the average scenario, the percentage of over-prediction by the ride quality model for pavement types ACP04 and ACP05 are, respectively, 53 percent and 17 percent (under-predicting, respectively, in 47 percent and 83 percent of observations). The average, optimistic, and pessimistic percentage values of over-prediction by the ride quality model as a family are 61 percent, 68 percent, and 54 percent, respectively. The average, optimistic, and pessimistic percentage values of under-prediction by the ride quality model as a family are 39 percent, 46 percent, and 32 percent, respectively. From this analysis it can be inferred that the ride quality model as a family is marginally over-predicting. The ride quality model for pavement type ACP04 is giving almost the average prediction; for the pavement type ACP05, it is generally under-predicting; and for pavement type ACP06, it is generally over-predicting.

However, since the number of observations for each pavement type (especially for ACP05) is small, analysis for individual pavement type cannot be considered representative.

Table 3.30 Percentage of Over-Prediction by Ride Quality Models

Pavement Type	Item	Over-prediction			Under-prediction		
		Optimistic Scenario	Average Scenario	Pessimistic Scenario	Optimistic Scenario	Average Scenario	Pessimistic Scenario
ACP04	Number of Prediction	22	17	12	20	15	10
	Percentage of Prediction	68.8	53.1	37.5	62.5	46.9	31.3
	Mean % Difference	10.5	8.9	8.3	15.1	13.6	12.7
	S. D. % Difference	8.0	6.8	5.3	18.0	17.1	17.2
ACP05	Number of Prediction	2	2	2	10	10	10
	Percentage of Prediction	16.7	16.7	16.7	83.3	83.3	83.3
	Mean % Difference	29.8	22.1	12.8	37.4	33.2	29.0
	S. D. % Difference	1.9	2.8	1.7	12.8	11.9	11.4
ACP06	Number of Prediction	26	26	26	4	4	4
	Percentage of Prediction	86.7	86.7	86.7	13.3	13.3	13.3
	Mean % Difference	19.7	15.7	11.5	42.9	38.8	34.4
	S. D. % Difference	7.0	6.4	6.5	12.4	10.8	9.6
Family	Number of Prediction	50	45	40	34	29	24
	Percentage of Prediction	67.6	60.8	54.1	45.9	39.2	32.4
	Mean % Difference	16.1	13.4	10.6	24.9	23.8	23.1
	S. D. % Difference	9.0	7.4	6.1	19.7	18.0	16.2

PMIS Alligator Cracking Model

Data Censorship - Figures D.17 through D.32 of Appendix D present plots of the observed alligator cracking (A), alligator cracking plus longitudinal cracking in the wheel paths (A+L), and the predicted alligator cracking versus pavement age for each section. The following data were removed from analyses of the alligator cracking model:

For alligator cracking only:

- Data for sections 1077 (figure D.21) and 9005 (figure D.32) at 12.8 years and 4.1 years, respectively, were found faulty.
- All data for section 1178 were considered a special case of swelling soil.

- For alligator cracking and longitudinal cracking in the wheel paths combined, data for sections 1060 (figure G.19), 1094 (figure G.22), and 9005 (figure G.32) at 9.0 years, 19.1 years, and 6.6 years, respectively, were found faulty.
- All data for section 1178 were considered a special case of swelling soil.

Trend Analysis - Table 3.31 presents the trends observed for each section. It shows that for only alligator cracking data and pavement type ACP04, trends are generally flatter than predicted. For pavement types ACP05 and ACP06, both flatter and steeper trends are found. For alligator cracking plus longitudinal cracking data, no particular trend can be established for each pavement type.

Table 3.31 Trends of Observed Alligator Cracking Data

Section	Pavement Type	Trend of Alligator Cracking	Trend of Alligator + Long. Cracking
1047	ACP04	Crossing Trend Flatter than Predicted	Crossing Trend Flatter than Predicted
1050	ACP06	Crossing Trend Steeper than Predicted	Crossing Trend Steeper than Predicted
1060	ACP04	Crossing Trend Flatter than Predicted	Crossing Trend Flatter than Predicted
1068	ACP04	Crossing Trend Flatter than Predicted	Crossing Trend Steeper than Predicted
1077	ACP05	Crossing Trend Flatter than Predicted	Crossing Trend Flatter than Predicted
1094	ACP06	Crossing Trend Flatter than Predicted	Scattered
1096	ACP04	Crossing Trend Flatter than Predicted	Crossing Trend Steeper than Predicted
1113	ACP06	Single Observation	Single Observation
1130	ACP05	Crossing Trend Steeper than Predicted	Crossing Trend Steeper than Predicted
1168	ACP06	Crossing Trend Steeper than Predicted	Crossing Trend Steeper than Predicted
3579	ACP06	Crossing Trend Flatter than Predicted	Crossing Trend Flatter than Predicted
3729	ACP04	Crossing Trend Flatter than Predicted	Crossing Trend Flatter than Predicted
3739	ACP06	Crossing Trend Flatter than Predicted	Crossing Trend Flatter than Predicted
3875	ACP06	Single Observation	Single Observation
9005	ACP06	Crossing Trend Steeper than Predicted	Crossing Trend Steeper than Predicted

Hypothesis Tests - Hypotheses tests were performed for each pavement section with more than two observations and where the data trend allowed. Tests were carried out with the observed alligator cracking as well as alligator cracking plus longitudinal cracking data and are presented, respectively, in tables E.2 and E.3 of Appendix E.

Using only alligator cracking data, seven sections could be tested out of 15 sections. The null hypothesis, "intercept is zero" was rejected for two sections (3729, 3739). The null hypothesis, "slope is one" was rejected for three sections (1050, 3579, 9005) and the null hypothesis, "correlation coefficient is zero" was rejected for six listed sections (1050, 1068, 3579, 3729, 3739, 9005). From the results of the hypotheses tests, it can be inferred that the performance model is predicting the observed alligator cracking for only one LTPP section (1068). There is no linear relationship between the predicted and observed values for section 1168, though it cannot be denied that the model is predicting the observed values at this LTPP site. For the remaining five sections tested it can be inferred that the model is not predicting the observed values, though for four sections some weak relationships between the predicted and observed values cannot be denied. However, due to the small sample size, these results cannot be considered representative. Tables 3.32 through 3.35 present hypotheses tests conducted on alligator cracking models for pavement types ACP04, ACP05, ACP06, and for the model as a family using only alligator cracking data. In all of these four cases, the null hypothesis, "intercept is zero" was rejected. The null hypothesis, "slope is one" could not be rejected for pavement types ACP04 and ACP05. The null hypothesis, "correlation coefficient is zero" could not be rejected in all four cases. From these results it can be inferred that none of the alligator cracking models (including as a family) is predicting the alligator cracking observed at the 15 LTPP sites. These results also do not indicate any linear relationship between the predicted and the observed values.

Hypotheses tests could be conducted on 12 individual sections using alligator cracking plus longitudinal cracking data. The null hypotheses, "intercept is zero" and "slope is one" could not be rejected simultaneously for six sections (1060, 1094, 1096, 3579, 3729, 3739). However, out of these six sections, the null hypothesis, "correlation coefficient is zero" could be rejected for only one section (3579). This implies that the model is predicting the combined cracking (alligator cracking plus longitudinal cracking) values observed only at

Table 3.32 Hypotheses Tests on Alligator Cracking Model for ACP04

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	27.562	-2.117	Correlation coeff.	-0.283
Standard Error	4.859	1.568	t-statistic	-1.350
t-statistic	5.673	-1.988	Degrees of freedom	21
Degrees of freedom	21	21	p-value (Prob>|r|)	0.191
p-value (Prob>|t|)	0.000	0.060	Reject H_0?	Can't Reject
Upper 95%	37.665	1.144	Difference: Mean	22.589
Lower 95%	17.458	-5.379	Std. Deviation	20.924
Reject H_0?	Can Reject	Can't Reject	Maximum	71.376
Regression Statistics:	R-square	0.0799	Minimum	0.103
	Root MSE	19.7840	No. of Observations	23

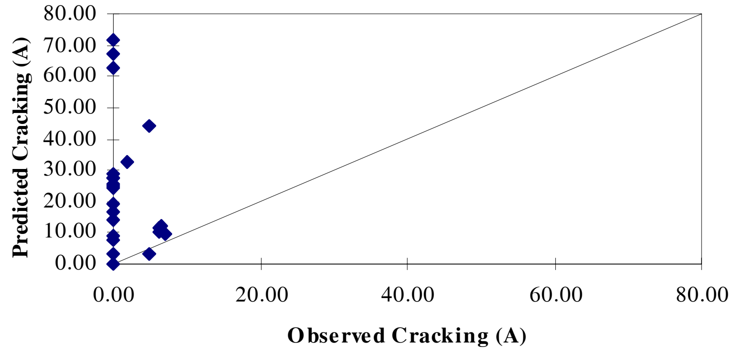


Table 3.33 Hypotheses Tests on Alligator Cracking Model for ACP05

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	36.793	0.449	Correlation coeff.	0.627
Standard Error	3.257	0.228	t-statistic	1.972
t-statistic	11.295	-2.418	Degrees of freedom	6
Degrees of freedom	6	6	p-value (Prob>|r|)	0.096
p-value (Prob>|t|)	0.000	0.052	Reject H_0?	Can't Reject
Upper 95%	44.763	1.007	Difference: Mean	32.956
Lower 95%	28.822	-0.108	Std. Deviation	10.468
Reject H_0?	Can Reject	Can't Reject	Maximum	45.310
Regression Statistics:	R-square	0.3933	Minimum	16.825
	Root MSE	8.0462	No. of Observations	8

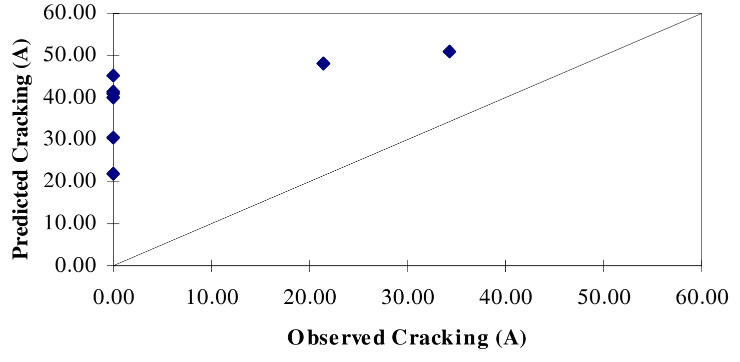


Table 3.34 Hypotheses Tests on Alligator Cracking Model for ACP06

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	4.032	-0.125	Correlation coeff.	-0.132
Standard Error	1.192	0.184	t-statistic	-0.677
t-statistic	3.382	-6.099	Degrees of freedom	26
Degrees of freedom	26	26	p-value (Prob>|r|)	0.505
p-value (Prob>|t|)	0.002	0.000	Reject H_0?	Can't Reject
Upper 95%	6.482	0.254	Difference: Mean	5.680
Lower 95%	1.581	-0.504	Std. Deviation	6.441
Reject H_0?	Can Reject	Can Reject	Maximum	16.469
Regression Statistics:	R-square	0.0173	Minimum	0.000
	Root MSE	5.3695	No. of Observations	28

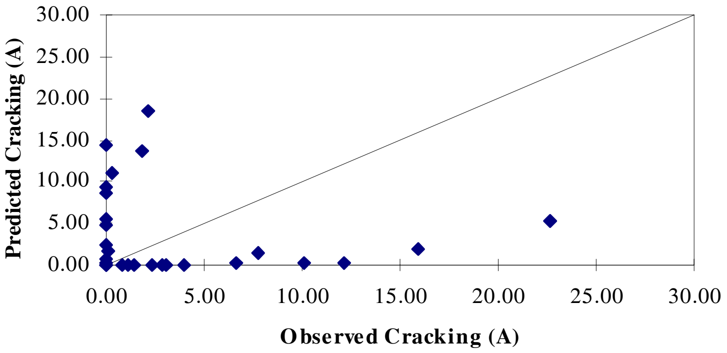
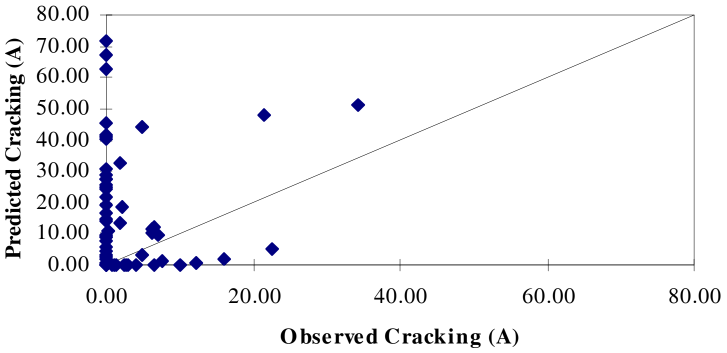


Table 3.35 Hypotheses Tests on Alligator Cracking Model as a Family

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	15.886	0.198	Correlation coeff.	0.068
Standard Error	2.766	0.386	t-statistic	0.513
t-statistic	5.744	-2.077	Degrees of freedom	57
Degrees of freedom	57	57	p-value (Prob>|r|)	0.610
p-value (Prob>|t|)	0.000	0.042	Reject H_0?	Can't Reject
Upper 95%	21.424	0.971	Difference: Mean	16.128
Lower 95%	10.348	-0.575	Std. Deviation	17.271
Reject H_0?	Can Reject	Can Reject	Maximum	71.376
Regression Statistics:	R-square	0.0046	Minimum	0.000
	Root MSE	19.0153	No. of Observations	59



the section 3579, and there is some linear relationship between the predicted and observed values. There are no linear relationships between the predicted and observed values at the other five sections, though it cannot be denied that the model is predicting the combined cracking values observed at these five sections. For the remaining six sections out of 12 sections tested, it can be inferred that the model is not predicting the combined cracking observed, although some weak relationship between the predicted and observed values cannot be denied at three sections (1068, 1077, 9005). However, due to the small sample size, these results can not be considered representative.

The same tests were also performed on the alligator cracking models for the pavement types ACP04, ACP05, ACP06, and the model as a family using combined data (alligator cracking plus longitudinal cracking). These are presented in tables 3.36 through 3.39. In all the cases, the null hypothesis, "intercept is zero" was rejected. The null hypothesis, "slope is one" could not be rejected for pavement type ACP05. The null hypothesis, "correlation coefficient is zero" was rejected only for pavement type ACP05. From these results, it can be inferred that none of the alligator cracking models (including the model as a family) is predicting the combined cracking values observed at the 12 sections, and there are no linear relationships between cracking values observed and predicted by the performance models for all pavement types (and the model as a family) except for pavement type ACP05.

Percent Difference - Table 3.40 presents the mean and standard deviation of percent differences, which were computed using the alligator cracking values predicted by the models for each pavement type (ACP04, ACP05, ACP06, and the model as a family) and the observed alligator cracking values. The mean and standard deviation of percent differences are approximately 86 percent and 25 percent, respectively, for both pavement types ACP04 and ACP05 in the average scenario. Even in the optimistic scenario, the mean percent difference is as high as 80 percent for both ACP04 and ACP05. The mean and standard deviation values for pavement type ACP06 and the model as a family are very large. The mean and standard deviation of percent differences computed using the observed alligator cracking and longitudinal cracking values are given in table 3.41. In the average scenario, the mean and standard deviation for pavement type ACP05 are, respectively, 58 percent and 19 percent. These values are lower than those for any other pavement types.

Table 3.36 Hypotheses Tests on Alligator Cracking Model for ACP04 (Using A+L Data)

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	26.675	-0.171	Correlation coeff.	-0.144
Standard Error	6.119	0.263	t-statistic	-0.651
t-statistic	4.359	-4.456	Degrees of freedom	20
Degrees of freedom	20	20	p-value (Prob>|r|)	0.522
p-value (Prob>|t|)	0.000	0.000	Reject H_0?	Can't Reject
Upper 95%	39.440	0.377	Difference: Mean	21.848
Lower 95%	13.910	-0.719	Std. Deviation	19.892
Reject H_0?	Can Reject	Can Reject	Maximum	65.963
Regression Statistics:	R-square	0.0208	Minimum	0.338
	Root MSE	20.8999	No. of Observations	22

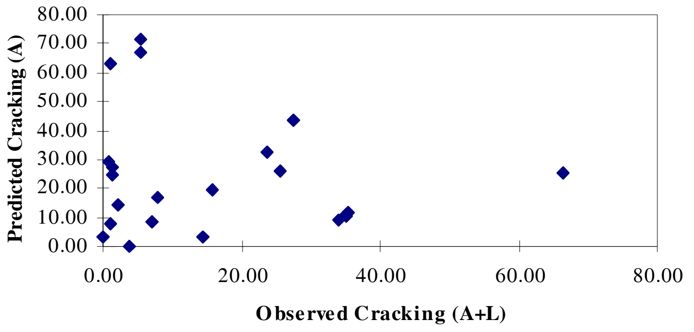


Table 3.37 Hypotheses Tests on Alligator Cracking Model for ACP05 (Using A+L Data)

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	24.967	0.827	Correlation coeff.	0.912
Standard Error	2.828	0.141	t-statistic	5.876
t-statistic	8.829	-1.230	Degrees of freedom	7
Degrees of freedom	7	7	p-value (Prob>|r|)	0.001
p-value (Prob>|t|)	0.000	0.259	Reject H_0?	Can Reject
Upper 95%	31.653	1.160	Difference: Mean	20.964
Lower 95%	18.280	0.494	Std. Deviation	4.669
Reject H_0?	Can Reject	Can't Reject	Maximum	27.232
Regression Statistics:	R-square	0.8314	Minimum	13.314
	Root MSE	3.9394	No. of Observations	9

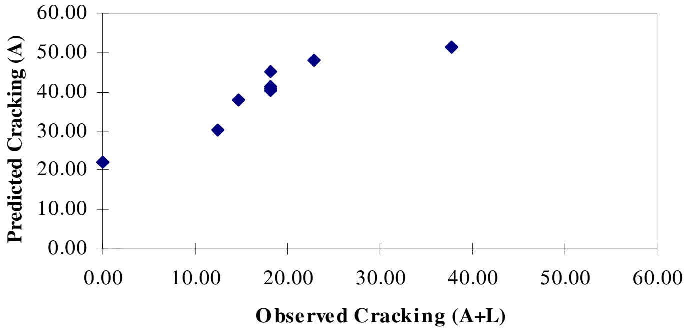


Table 3.38 Hypotheses Tests on Alligator Cracking Model for ACP06 (Using A+L Data)

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	4.154	-0.089	Correlation coeff.	-0.202
Standard Error	1.324	0.086	t-statistic	-1.031
t-statistic	3.137	-12.617	Degrees of freedom	25
Degrees of freedom	25	25	p-value (Prob>|r|)	0.312
p-value (Prob>|t|)	0.004	0.000	Reject H_0?	Can't Reject
Upper 95%	6.882	0.089	Difference: Mean	10.416
Lower 95%	1.427	-0.267	Std. Deviation	10.907
Reject H_0?	Can Reject	Can Reject	Maximum	35.178
Regression Statistics:	R-square	0.0408	Minimum	0.000
	Root MSE	4.9625	No. of Observations	27

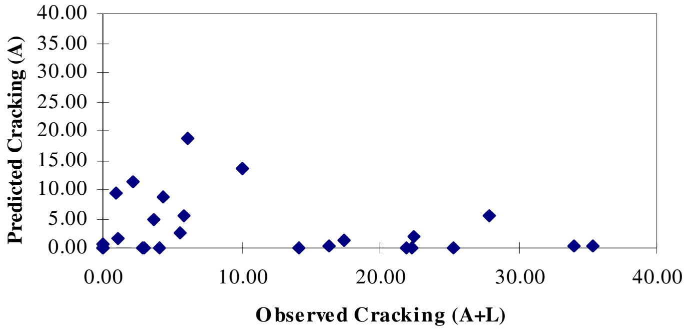


Table 3.39 Hypotheses Tests on Alligator Cracking Model as a Family (Using A+L Data)

Null Hypothesis (H_0):	Intercept (B_0)=0	Slope (B_1)=1	Null Hypothesis (H_0):	Corr. Coef (r)=0
Regression Coeffs	14.722	0.146	Correlation coeff.	0.105
Standard Error	3.583	0.184	t-statistic	0.793
t-statistic	4.109	-4.632	Degrees of freedom	56
Degrees of freedom	56	56	p-value (Prob>|r|)	0.431
p-value (Prob>|t|)	0.000	0.000	Reject H_0?	Can't Reject
Upper 95%	21.900	0.515	Difference: Mean	16.389
Lower 95%	7.544	-0.223	Std. Deviation	15.324
Reject H_0?	Can Reject	Can Reject	Maximum	65.963
Regression Statistics:	R-square	0.0111	Minimum	0.000
	Root MSE	19.2711	No. of Observations	58

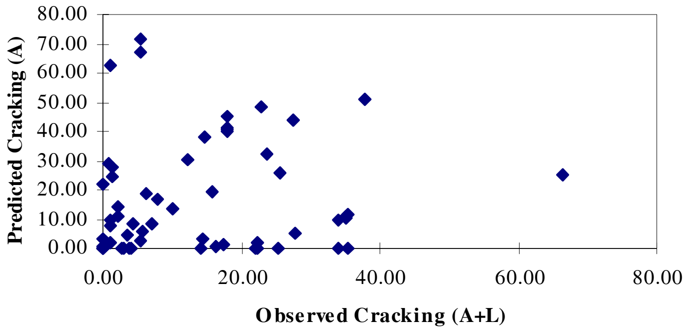


Table 3.40 Percent Difference for Alligator Cracking Models

Pavement Type	Item	Optimistic Scenario	Average Scenario	Pessimistic Scenario
ACP04	Number of Prediction	23	23	23
	Percentage of Prediction	100	100	100
	Mean % Difference	80.9	86.2	94.9
	S. D. % Difference	34.7	25.3	12.7
ACP05	Number of Prediction	8	8	8
	Percentage of Prediction	100	100	100
	Mean % Difference	79.2	86.0	92.9
	S. D. % Difference	39.5	26.5	13.4
ACP06	Number of Prediction	28	28	28
	Percentage of Prediction	100	100	100
	Mean % Difference	**	**	**
	S. D. % Difference	**	**	**
Family	Number of Prediction	59	59	59
	Percentage of Prediction	100	100	100
	Mean % Difference	**	**	**
	S. D. % Difference	**	**	**

Table 3.41 Percent Difference for Alligator Cracking Models (A+L Data)

Pavement Type	Item	Optimistic Scenario	Average Scenario	Pessimistic Scenario
ACP04	Number of Prediction	22	22	22
	Percentage of Prediction	100	100	100
	Mean % Difference	140	267	404
	S. D. % Difference	355	726	1096
ACP05	Number of Prediction	9	9	9
	Percentage of Prediction	100	100	100
	Mean % Difference	40.3	58.4	79.0
	S. D. % Difference	24.3	18.9	9.6
ACP06	Number of Prediction	27	27	27
	Percentage of Prediction	100	100	100
	Mean % Difference	**	**	**
	S. D. % Difference	**	**	**
Family	Number of Prediction	58	58	58
	Percentage of Prediction	100	100	100
	Mean % Difference	8783	**	**
	S. D. % Difference	**	**	**

Note: ** indicates very large (>> 10,000)

Since percent difference can be very large if computed with respect to a very small value, a large value of percent difference is possible even when the difference is small. For this reason the mean and standard deviation of differences were also computed. The mean values of differences (in percent wheel path) between the predicted and observed alligator cracking values for pavement types ACP04, ACP05, ACP06 and the model as a family were 23, 33, 6, and 16, respectively. The standard deviation values corresponding to the above mean values were 21, 10, 6, and 17, respectively. Using the combined cracking data, the mean values of differences were calculated as 22, 21, 10, and 16, respectively for pavement types ACP04, ACP05, ACP06, and the model as a family. The corresponding standard deviation values were calculated as 20, 5, 11, and 15, respectively. Table 1.4 of reference 1 defines levels of service for alligator cracking used by the PMIS. The levels of service are "Desirable," "Acceptable," "Tolerable," and "Intolerable" corresponding to alligator cracking area (in percent wheel path) less than 1, 1-10, 11-50, and 51-100, respectively (1). Therefore, it is impossible to identify the difference among the first three levels of service from the alligator cracking values predicted by the existing performance models.

Percent Over-predicting - Table 3.42 presents the percentage values of over- and under-prediction by the alligator cracking models for pavement types ACP04, ACP05, ACP06, and all pavement types combined in optimistic, pessimistic, and average scenarios. The percentage of over-prediction by the alligator cracking model is 96 percent for pavement type ACP04, 100 percent for pavement type ACP05, 54 percent for pavement type ACP06, and 76 percent for all pavement types combined. From this analysis it can be inferred that the model is over-predicting in general. These estimates of over-prediction are computed using the observed alligator cracking data. The percentage of over-prediction (table 3.42) computed using alligator cracking plus longitudinal cracking data for pavement types ACP04, ACP05, ACP06, and all pavement types combined are 68 percent, 100 percent, 44 percent, and 62 percent, respectively. These figures show that the model is marginally over-predicting in general. Since nine observations were available for ACP05, the 100 percent over-prediction figure cannot be considered representative.

Table 3.42 Percentage of Over-Prediction by Alligator Cracking Models

Pavement Type	Item	Percent Over-prediction						Percent Under-prediction					
		Only Alligator Cracking Data			Alligator + Long. Cracking Data			Only Alligator Cracking Data			Alligator + Long. Cracking Data		
		Optimistic Scenario	Average Scenario	Pessimistic Scenario	Optimistic Scenario	Average Scenario	Pessimistic Scenario	Optimistic Scenario	Average Scenario	Pessimistic Scenario	Optimistic Scenario	Average Scenario	Pessimistic Scenario
ACP04	Number of Prediction	23	22	21	15	15	11	2	1	0	11	7	7
	Percentage of Prediction	100.0	95.7	91.3	68.2	68.2	50.0	8.7	4.3	0.0	50.0	31.8	31.8
	Mean % Difference	91.1	88.1	86.7	82.8	66.0	76.5	62.9	43.5	-	703.7	697.6	304.0
	S. D. % Difference	18.3	24.1	30.0	18.3	36.1	30.6	72.8	-	-	1525.3	1233.9	625.0
ACP05	Number of Prediction	8	8	7	9	9	8	1	0	0	1	0	0
	Percentage of Prediction	100.0	100.0	87.5	100.0	100.0	88.9	12.5	0.0	0.0	11.1	0.0	0.0
	Mean % Difference	92.9	86.0	90.5	79.0	58.4	44.0	0.2	-	-	10.5	-	-
	S. D. % Difference	13.4	26.5	25.1	9.6	18.9	23.0	-	-	-	-	-	-
ACP06	Number of Prediction	15	15	15	13	12	10	13	13	13	17	15	14
	Percentage of Prediction	53.6	53.6	53.6	48.1	44.4	37.0	46.4	46.4	46.4	63.0	55.6	51.9
	Mean % Difference	98.9	97.8	96.8	83.1	72.5	73.1	**	**	**	**	**	**
	S. D. % Difference	2.2	4.4	6.5	18.5	31.1	36.2	**	**	**	**	**	**
Family	Number of Prediction	46	45	43	37	36	29	16	14	13	29	22	21
	Percentage of Prediction	78.0	76.3	72.9	63.8	62.1	50.0	27.1	23.7	22.0	50.0	37.9	36.2
	Mean % Difference	94.0	91.0	90.9	82.0	66.3	66.4	**	**	**	**	**	**
	S. D. % Difference	16.0	21.6	24.6	17.7	30.5	33.1	**	**	**	**	**	**

Note: ** indicates very large (>> 10,000)

PMIS Shallow Rutting Model

Figures D.33 through D.46 in Appendix D present the plots of the observed and predicted shallow rutting versus pavement age for each section. Section 1178 was excluded from the analysis because of the special effect of swelling soil. Due to a very limited number of observations for each section, trend analysis and hypotheses tests could not be performed for each section and each pavement type. Hypotheses were tested for the shallow rutting family using all data combined. As previously described, the observed rut depth values were converted to shallow rutting (in percent wheel path) using two methods: 1) linear method and 2) point method. Table 3.43 presents hypotheses tests performed using the observed shallow rutting values computed employing the linear method. It shows that the null hypotheses, “intercept is zero,” “slope is one,” and “correlation coefficient is zero” were rejected. Hypotheses tests performed using data computed employing the point method also indicate the same results. This implies that the performance model is not predicting the shallow rutting values converted from the rut depth values observed at the LTPP sites, although some linear relationship between the predicted and observed values cannot be denied. The mean and standard deviation of differences (in percent wheel path) between the observed (converted using the linear method) and predicted values are 12.7 and 13.3, respectively. The mean and standard deviation of differences (in percent wheel path) between the observed (converted using the point method) and predicted values are 13.2 and 13.7, respectively. Table 61 shows that the observed shallow rutting values are less than the predicted values in 25 out of 26 observations. From this result it can be inferred that the shallow rutting model is consistently over-predicting the shallow rutting observed at the LTPP sites. However, since only 26 observations could be used in the analysis, the above estimates cannot be considered representative.

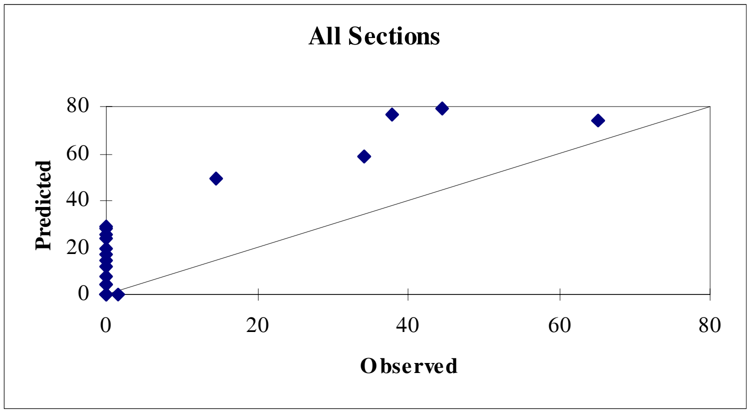
PMIS Deep Rutting Model

Similar to shallow rutting, analyses on the deep rutting model could not be performed on each section and pavement type due to the lack of data. Figures D.47 through D.60 of

Table 3.43 Hypotheses Tests on Shallow Rutting Model Family

SHRP ID	Age	SHALLOW RUT Observed	SHALLOW RUT Predicted	Difference (Obs-Pre)
	years	%WP	%WP	%WP
1050	5.4	0.0	0.0	0.0
1050	5.9	0.0	0.1	0.1
1050	8.0	0.0	4.0	4.0
1060	5.1	0.0	12.2	12.2
1060	6.1	0.0	25.8	25.8
1068	4.1	0.0	0.2	0.2
1077	14.5	65.2	73.9	8.7
1094	13.0	0.0	7.6	7.6
1094	14.7	0.0	14.8	14.8
1094	15.2	0.0	17.3	17.3
1096	10.0	0.0	27.7	27.7
1113	5.5	0.0	0.0	0.0
1130	18.7	37.8	76.8	39.0
1130	19.6	44.5	79.4	34.9
1168	5.8	1.7	0.0	2
3579	3.6	0.0	0.0	0.0
3579	5.1	0.0	0.0	0.0
3579	7.7	0.0	4.6	4.6
3729	7.9	14.5	49.5	35.0
3729	8.8	34.3	59.1	24.8
3739	8.9	0.0	19.9	19.9
3739	9.3	0.0	23.6	23.6
3739	9.9	0.0	28.7	28.7
9005	4.1	0.0	0.0	0.0
9005	4.6	0.0	0.0	0.0
9005	9.5	0.0	0.3	0.3
			Mean =	12.7
			Std. Deviation =	13.3

Graph of Observed Vs. Predicted Shallow Rutting



TESTING OF HYPOTHESES

Null Hypothesis (H_0):	$B_0=0$	$B_1=1$
Regression Coeffs	10.114	1.325
Standard Error	2.669	0.143
t-statistic	3.790	2.274
Degrees of freedom	24	24
p value (Prob>| t |)	0.001	0.032
Upper 95%	15.622	1.621
Lower 95%	4.605	1.030
Reject H_0?	Reject	Reject
Regression Statistics:		
R-square =	0.781	
Root MSE =	12.423	
Observations =	26	

Null Hypothesis (H_0):	r=0
Correlation coeff.	0.884
t-statistic	9.265
Degrees of freedom	24
p-value (Prob>| r |)	0.000
Reject H_0?	Reject

Remarks:

- o Mean and std. deviation of difference are large.
- o Very large root MSE.
- o Null hypothesis of slope=1 and intercept=0 can be rejected.

Notes:

1. Shallow rutting values computed using the linear method are used as observed data.
2. Observed data obtained using the point method gives overall mean and std. deviation of difference as 13.2 and 13.7 percent, respectively.
3. With observed data from the point method, **p**-values of **t**-statistic for null hypotheses intercept=0 slope=1, and corr.coef=0 are 0.002, 0.014, and 0.000, respectively. Hence null hypotheses can be rejected.
4. 25 out of 26 predictions are more than or equal to the observed values.

Appendix D show the plots of the observed (computed using both the linear and point methods) and the predicted deep rutting (in percent wheel path) versus pavement age for each section. Table 3.44 presents the hypotheses tests on the combined data. The project performed tests results rejected the hypothesis in both cases, as shown in table 3.44. From the results of the hypotheses tests it can be inferred that the performance model is not predicting the deep rutting values computed (using both methods) from the rut depth values observed at the LTPP sites. The mean and standard deviation of differences between the predicted and observed deep rutting computed using the linear method are 10.2 and 8.7 (in percent wheel path), respectively. The mean and standard deviation of difference between the predicted and observed deep rutting computed using the point method are 9.9 and 8.1, respectively. Since there are no predictions less than the observed deep rutting, it can be inferred that the deep rutting model is over-predicting the deep rutting values observed at the LTPP sites. However, the estimates cannot be considered representative because of the small sample size (26 observations).

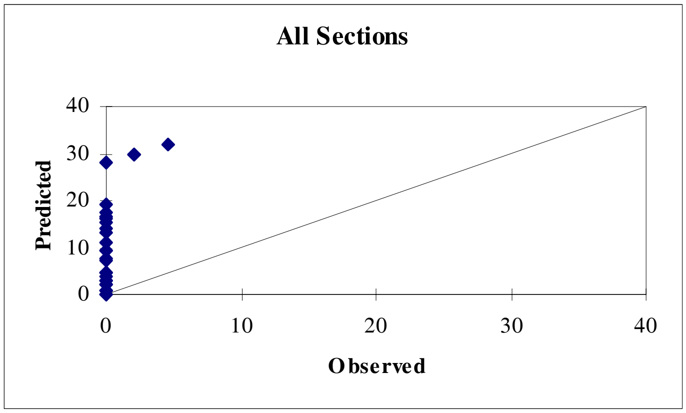
General Inference on PMIS Models

It may be found in table 3.45 that the PMIS subgrade classes based on the county number do not match well with the subgrade moduli back-calculated from the LTPP FWD data tested on sections located in the same county. The average back-calculated modulus of subgrade classified as "poor" is greater than the values for those classified as "good" and "fair." The average back-calculated modulus of subgrade classified as "fair" is also greater than the values for those classified as "good." If the subgrade moduli recommended by FPS-19 is considered, then all observations classified as "fair" and five observations (out of eight) classified as "poor" should be in "very good" and all observations classified as "very poor" should be classified as "good." Since PMIS subgrade classification is a part of the performance models, this classification may have contributed to the poor predictive capabilities of all PMIS models analyzed.

Table 3.44 Hypotheses Tests on Deep Rutting Model Family

SHRP ID	Age	DEEP RUT Observed	DEEP RUT Predicted	Difference (Obs-Pre)
	years	%WP	%WP	%WP
1050	5.4	0.0	2.8	2.8
1050	5.9	0.0	3.9	3.9
1050	8.0	0.0	9.2	9.2
1060	5.1	0.0	4.5	4.5
1060	6.1	0.0	7.3	7.3
1068	4.1	0.0	0.9	0.9
1077	14.5	0.0	27.9	27.9
1094	13.0	0.0	11.2	11.2
1094	14.7	0.0	14.2	14.2
1094	15.2	0.0	15.2	15.2
1096	10.0	0.0	7.7	7.7
1113	5.5	0.0	2.0	2.0
1130	18.7	2.0	29.9	27.9
1130	19.6	4.6	31.8	27.2
1168	5.8	0.0	2.1	2.1
3579	3.6	0.0	0.7	0.7
3579	5.1	0.0	2.9	2.9
3579	7.7	0.0	9.5	9.5
3729	7.9	0.0	13.3	13.3
3729	8.8	0.0	16.5	16.5
3739	8.9	0.0	16.2	16.2
3739	9.3	0.0	17.4	17.4
3739	9.9	0.0	19.2	19.2
9005	4.1	0.0	0.1	0.1
9005	4.6	0.0	0.2	0.2
9005	9.5	0.0	4.9	4.9
			Mean =	10.2
			Std. Deviation =	8.7

Graph of Observed Vs. Predicted Deep Rutting



TESTING OF HYPOTHESES

Null Hypothesis (H_0):	B_0=0	B_1=1	Null Hypothesis (H_0):	r=0
Regression Coeffs	8.963	5.829	Correlation coeff.	0.608
Standard Error	1.530	1.555	t-statistic	3.749
t-statistic	5.859	3.105	Degrees of freedom	24
Degrees of freedom	24	24	p-value (Prob>| r |)	0.001
p value (Prob>| t |)	0.000	0.005	Reject H_0?	Reject
Upper 95%	12.120	9.039		
Lower 95%	5.805	2.620		
Reject H_0?	Reject	Reject		
Regression Statistics:				
	R square =	0.369		
	Root MSE =	7.536		
	Observations =	26		

Remarks:

o Mean and std. deviation of difference are large.

o Large standard error.

o Null hypothesis of slope=1 and intercept=0 can be rejected.

Notes:

1. Deep rutting values computed using the linear method are used as observed data.
2. Observed data obtained using the point method gives overall mean and std. deviation of difference as 9.9 and 8.1 percent, respectively.
3. With observed data from the point method, **p**-values of **t**-statistic for null hypotheses intercept=0 slope=1, and corr.coef=0 are 0.000, 0.024, and 0.001, respectively. Hence the null hypotheses can be rejected.
4. There are no predictions less than the observed deep rutting values.

Table 3.45 PMIS Subgrade Classes and Back-Calculated Subgrade Moduli

PMIS Subgrade Class	PMIS County Number	LTPP Section Number	Subgrade Modulus Recommended by FPS-19 (in ksi)	Back-Calculated Subgrade Modulus (in ksi)
Very Good	15	1094, 9005	20.0	29.9, 28.4
Good	163	1096	16.0	16.4
Fair	201, 95, 250	1113, 1130, 1168	12.0	22.6, 22.9, 18.7
Poor	33, 94, 139, 97, 26, 234, 66, 211	1047, 1050, 1068, 1077, 1178, 3579, 3739, 3875	8.0	19.0, 22.7, 18.9, 25.3, 23.5, 26.5, 15.1, 38.5
Very Poor	196, 31	1060, 3729	4.0	16.7, 15.0

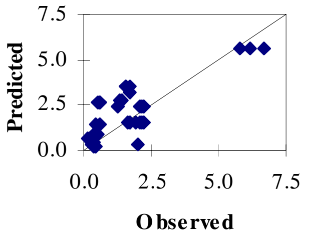
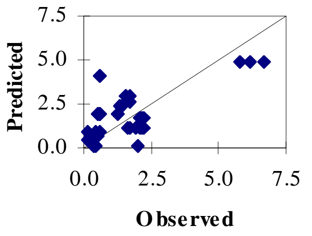
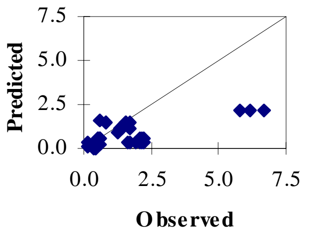
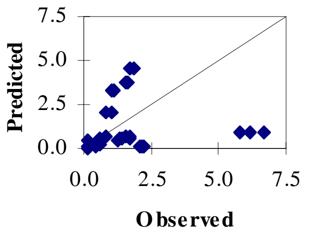
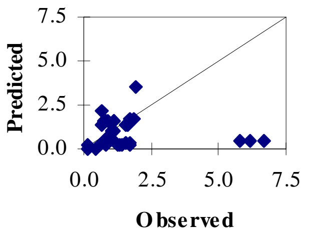
FPS-19

The results from various analyses performed using ESAL values observed at the LTPP sites and predicted by FPS-19 for reliability levels A through E and the inferences made from these results are given below.

Data Censorship - Data excluded for FPS-19 were the same as those for the PMIS ride quality model.

Hypothesis Tests - Table 3.46 presents the results of hypotheses tested for each reliability level. Since FPS-19 does not provide any solution if the performance period is less than one year or more than 40 years, the sample sizes are different at each reliability level. Table 3.46 shows that the null hypotheses, "intercept is zero" and "slope is one" were rejected for all reliability levels. The null hypothesis, "correlation coefficient is zero" was rejected for reliability levels A, B, and C. From the results of the hypotheses tests it can be inferred that at all reliability levels, FPS-19 is not predicting the ESAL values observed at the LTPP sites, although some linear relationships between the ESAL values observed and predicted at reliability levels A, B, and C cannot be denied.

Table 3.46 Hypotheses Tests on FPS-19

Reliability Level	Graph of Observed Vs. Predicted ESAL	TESTING OF HYPOTHESES / REMARKS				
		Null Hypothesis (H_0):	B_0=0	B_1=1	Null Hypothesis (H_0):	r=0
A (80%)		Regression Coeffs	1.083	0.691	Correlation coeff.(r)	0.756
		Standard Error	0.221	0.101	t-statistic	6.841
		t-statistic	4.904	-3.052	Degrees of freedom	35
		Degrees of freedom	35	35	p-value (Prob>| r |)	0.000
		p-value (Prob>| t |)	0.000	0.004	Reject H_0?	Reject
		Upper 95%	1.531	0.897		
		Lower 95%	0.635	0.486		
		Reject H_0?	Reject	Reject		
		Regression Statistics:				
			R-square =	0.572		
			Root MSE =	0.949		
			Observations =	37		
B (90%)		Regression Coeffs	0.836	0.597	Correlation coeff.(r)	0.717
		Standard Error	0.204	0.096	t-statistic	6.252
		t-statistic	4.107	-4.212	Degrees of freedom	37
		Degrees of freedom	37	37	p-value (Prob>| r |)	0.000
		p-value (Prob>| t |)	0.000	0.000	Reject H_0?	Reject
		Upper 95%	1.248	0.791		
		Lower 95%	0.423	0.404		
		Reject H_0?	Reject	Reject		
		Regression Statistics:				
			R-square =	0.514		
			Root MSE =	0.911		
			Observations =	39		
C (95%)		Regression Coeffs	0.326	0.280	Correlation coeff.(r)	0.683
		Standard Error	0.107	0.050	t-statistic	5.618
		t-statistic	3.054	-14.414	Degrees of freedom	36
		Degrees of freedom	36	36	p-value (Prob>| r |)	0.000
		p-value (Prob>| t |)	0.004	0.000	Reject H_0?	Reject
		Upper 95%	0.543	0.382		
		Lower 95%	0.110	0.179		
		Reject H_0?	Reject	Reject		
		Regression Statistics:				
			R-square =	0.467		
			Root MSE =	0.471		
			Observations =	38		
D (99%)		Regression Coeffs	1.188	0.038	Correlation coeff.(r)	0.040
		Standard Error	0.349	0.162	t-statistic	0.236
		t-statistic	3.407	-5.936	Degrees of freedom	34
		Degrees of freedom	34	34	p-value (Prob>| r |)	0.815
		p-value (Prob>| t |)	0.002	0.000	Reject H_0?	Can't
		Upper 95%	1.897	0.368		
		Lower 95%	0.479	-0.291		
		Reject H_0?	Reject	Reject		
		Regression Statistics:				
			R-square =	0.002		
			Root MSE =	1.474		
			Observations =	36		
E (99.9%)		Regression Coeffs	0.997	-0.053	Correlation coeff.(r)	-0.102
		Standard Error	0.192	0.089	t-statistic	-0.590
		t-statistic	5.190	-11.766	Degrees of freedom	33
		Degrees of freedom	33	33	p-value (Prob>| r |)	0.559
		p-value (Prob>| t |)	0.000	0.000	Reject H_0?	Can't
		Upper 95%	1.388	0.129	**Remarks:**	
		Lower 95%	0.606	-0.235		
		Reject H_0?	Reject	Reject		
		Regression Statistics:				
			R-square =	0.010		
			Root MSE =	0.789		
			Observations =	35		

Percent Difference - The mean and standard deviation of percent differences between the observed and predicted ESALs were computed for optimistic, average, and pessimistic scenarios in the same manner previously described. Since there are no solutions for several terminal SIs, only those observations were considered for which there are solutions for all three scenarios. The percent difference data given in table 3.47 shows that the mean and standard deviation of percent differences are increasing as the reliability is increasing. This is true for all scenarios. In the average scenario, the mean and standard deviation of percent differences are, respectively, 62 percent and 93 percent for reliability level A (80 percent) and 300 percent and 417 percent for reliability level E (99.9 percent). Even in the optimistic scenario, the mean and standard deviation of percent differences for the reliability level A are 32 percent and 16 percent, respectively. These values are the lowest among all computed mean and standard deviation values.

Reliability - The reliability of design provided by FPS-19 was estimated as the percentage of observations in which the predicted ESAL values were not more than the observed ESAL values. Table 3.47 shows that the reliability values FPS-19 uses to predict ESALs are more than the corresponding estimated reliability values (computed comparing the predicted and observed ESALs). For example, the estimated reliability values calculated from the observed ESALs and ESALs predicted by FPS-19 at reliability level A (80 percent) is 38 percent in the average scenario (63 percent in the optimistic scenario). In the average scenario, the estimated reliability of predictions corresponding to reliability levels B, C, D, and E are 44 percent, 83 percent, 65 percent, and 70 percent, respectively. Even in the optimistic scenario, the estimated reliability values corresponding to the reliability levels B, C, D, and E are 67 percent, 89 percent, 75 percent, and 85 percent, respectively. However, these estimated reliability values cannot be considered representative as the sample sizes were small (18 to 33).

General Inference on FPS-19

FPS-19 needs initial and terminal serviceability indexes to predict performance periods. It recommends some terminal SIs according to the functional type, and that the statewide average initial SI is 4.2 for asphalt concrete flexible pavement and 3.8 for surface

Table 3.47 Percent Difference and Estimated Reliability of FPS-19

Reliability Level	Item	PERCENT DIFFERENCE			OBSERVED => PREDICTED		
		SCENARIOS			SCENARIOS		
		Optimistic	Average	Pessimistic	Optimistic	Average	Pessimistic
A (80%)	Number of Prediction =	24	37	24	15	9	2
	Percentage of Prediction =	100.0	100.0	100.0	62.5	37.5	8.3
	Group Statistics:						
	Mean % Difference =	32.4	61.5	79.6	80.3	22.2	19.3
	Std. Dev. of % Difference =	16.0	93.4	48.0	63.5	16.2	21.5
B (90%)	Number of Prediction =	27	39	27	18	12	7
	Percentage of Prediction =	100.0	100.0	100.0	66.7	44.4	25.9
	Group Statistics:						
	Mean % Difference =	39.6	90.5	111.3	141.2	48.8	27.6
	Std. Dev. of % Difference =	27.8	203.8	71.3	69.8	28.5	24.2
C (95%)	Number of Prediction =	18	38	18	16	15	14
	Percentage of Prediction =	100.0	100.0	100.0	88.9	83.3	77.8
	Group Statistics:						
	Mean % Difference =	67.2	197.4	203.9	223.4	101.3	71.5
	Std. Dev. of % Difference =	69.9	240.8	220.0	226.4	101.4	78.8
D (99%)	Number of Prediction =	20	36	20	15	13	13
	Percentage of Prediction =	100.0	100.0	100.0	75.0	65.0	65.0
	Group Statistics:						
	Mean % Difference =	145.3	279.3	231.7	282.8	257.6	202.1
	Std. Dev. of % Difference =	145.3	380.5	227.7	243.8	210.2	152.2
E (99.9%)	Number of Prediction =	33	35	33	28	23	16
	Percentage of Prediction =	100.0	100.0	100.0	84.8	69.7	48.5
	Group Statistics:						
	Mean % Difference =	281.4	300.3	500.5	580.1	409.9	538.5
	Std. Dev. of % Difference =	407.5	417.3	640.6	665.6	473.7	465.9

Note:

Estimated reliability is the percentage of predictions with observed ESAL => predicted ESAL treated flexible pavement. For evaluation purposes, initial SIs were considered 4.5 for ACP04 and ACP05 and 4.2 for ACP06. Since the initial SI has a very low sensitivity (reported in Chapter 3) towards prediction of performance period, it can be concluded that the errors of predictions due to the assumed values of the initial SIs were minimal.

From the predicted ESAL values at two different reliability levels, the average ESAL value that gives 50 percent reliability and the standard deviation can be obtained by solving two simultaneous equations. For example, if the predicted ESAL values with 80 percent (level A) and 90 percent (level B) reliability are, respectively, 5.598 and 4.839 million, the average ESAL value that gives 50 percent reliability and the standard deviation can be calculated as 7.398 million and 0.1438 million, respectively. However, for a few cases selected at random, it was found that the average ESAL values computed from the ESAL values corresponding to any two reliability levels are substantially different. The average ESAL (at 50 percent reliability) values and the standard deviation computed for section 1047 at age 20.3 are given in table 3.48 as a typical example where, table 3.48 shows that the standard deviation computed from ESAL values at reliability levels A and B is 0.1438 million, whereas the standard deviation computed from ESAL values at reliability levels B and C is 0.9413 million. Similarly the average ESAL value computed from ESAL values at reliability levels A and B is 7.398 million, whereas the same computed from ESAL values at reliability levels

Table 3.48 Typical Average ESAL Values

Reliability Level	Predicted ESAL (million)	Std. Deviation (million)	Average ESAL (million)	Std. Dev from FPS-19
A	5.598			0.5311
		0.1438	7.398	
B	4.839			
		0.9410	77.765	
C	2.202			
		0.5854	20.218	
D	0.879			
		0.4205	8.361	
E	0.420			

B and C is 77.765 million. It was also found that these computed standard deviations are significantly different from the standard deviation (0.5311) computed using the equation followed in FPS-19. The variation of the average ESALs from 7 to 77 million raises concerns. This error cannot be due only to the rounding of performance period by FPS-19 while reporting. The percentage difference in back-calculated predicted ESAL (N_e) due to the rounding of performance period (t) to nearest year can be expressed approximately as:

$$P = \frac{20.25 + t}{(40 + t)t} \quad for\ r_C/r_0 = 2 \tag{3.8}$$

P = percent difference in ESAL (N_e) due to rounding of performance period,
t = performance period,
r_0 = initial ADT, and
r_C = terminal ADT.

The percent differences are approximately 26 percent, 18 percent, and 6 percent, respectively, for performance periods (t) of two years, three years, and 10 years. These differences do not explain the variations found in table 3.48. To find a reasonable answer, two sets of output with predicted performance periods at all reliability levels were selected at random, and the process followed by FPS-19 to compute the performance periods was simulated. FPS-19 predicts the ESAL at 50 percent reliability (but does not display the value) using the serviceability model, computes the ESALs at the selected reliability level, and computes the performance period using Equation 3.6. Therefore, an iterative process was set up, where the ESAL at 50 percent reliability level was varied so that the computed performance periods, for all reliability levels, when rounded match exactly with the FPS-19 output. In so doing, it was found that the computation at level B could match with the output if its reliability were taken as 85 percent instead of 90 percent, which is displayed by FPS-19.

Although there are some percentage errors due to the rounding of performance period, which can be a maximum of 52 percent for a performance period of one year and 26 percent for a performance period of two years, it can be inferred that FPS-19 is not accurately predicting performance. This lack of accuracy is because only a very few one- and two-year performance periods were used in the evaluation, whereas the average percent difference was much more than 52 percent.

CONCLUSIONS AND RECOMMENDATIONS RELATED TO FLEXIBLE PAVEMENT MODELS

PMIS Models Conclusions

From the analyses and inference for the ride quality models, it can be concluded that the PMIS models are not predicting the ride quality values observed at the LTPP sites and should be improved, though some models are giving better predictions than the others. The ride quality models for pavement types ACP05 and ACP06 do not predict the values observed at the LTPP sites. The ride quality model for pavement type ACP04 gives better predictions of the observed ride quality, but it could be improved.

The predictions by the alligator cracking models are closer to the observed data if longitudinal cracking in the wheel paths is considered as fatigue cracking and added to alligator cracking data. Even then, the alligator cracking models for pavement types ACP04, ACP05, and ACP06 are not predicting the values observed at the LTPP sites. Based on analyses of individual members as well as the model as a whole, it can be concluded that the alligator cracking model is not predicting the values observed at the LTPP sites and should be improved.

Based on the difference and hypotheses test results, it can be concluded that the shallow rutting and deep rutting model families are over-predicting, and not predicting the values observed at the LTPP sites. These model families should also be improved.

FPS-19 Conclusions

From analyses and inferences it can be concluded that FPS-19 does not provide good predictions of the ESAL values observed at the LTPP sites and should be improved. However, since the predicted ESAL values were back-calculated from the predicted performance periods and there may be some errors associated with these predictions due to the rounding of performance periods, FPS-19 cannot be simply rejected without evaluating it using the originally predicted (and not back-calculated) ESALs. The program needs to be modified to obtain this additional output.

Therefore, it can be concluded that in order to integrate the performance models used by TxDOT at network and project level, all performance models evaluated in this study must be improved.

PMIS Recommendations

The following points may be considered for the improvement of the PMIS performance models:

- The general sigmoidal form is an adequate representation of the progression of damage indicated by performance measures (variation of pavement condition).
- The performance models can be improved by incorporating horizontal (δ) and vertical (γ) shift factors in the original equation. The revised equation would be:

$$L_i = \gamma + \alpha e^{-\left(\frac{\chi\rho}{AGE_i - \delta}\right)^{\beta}} \qquad (3.9)$$

where:

α = alpha, a horizontal asymptote factor that controls the maximum range of percentage distress growth or ride loss;

e = base of the natural logarithms (e˜ 2.71828...);

δ = delta, horizontal shift factor controlling the age at which the first sign of distress appears, for example, on a thin overlay, shallow rutting might not appear until year 3;

γ = gamma, vertical shift factor giving the initial level of the “distress” if this is non-zero, for instance there will always be an average crack spacing, even in a new CRCP;

ρ = rho, a prolongation factor, in years, that controls how long the pavement will last before significant increases in distress occur;

χ = chi, a modifying factor for rho that accounts for a change in projection based on observed performance;

β = beta, a slope factor that controls how steeply condition is lost in the middle of the curve; and

AGE = pavement section age, in years.

- In the absence of a consistent trend for a performance model family, the horizontal and vertical shift factors may be computed for each section and stored in the database for future prediction.
- Subgrade modulus should be incorporated in the PMIS performance models as an independent variable in place of the sigma factor.
- It was found that by changing equation 3.5 for the computation of loss of ride quality (changing from 4.8 to 4.5 and increasing RS_{min} by 1.0), the mean and standard deviation of difference were reduced from 0.61 and 0.39 to 0.47 and 0.34, respectively. In addition, equation 3.1, used for converting roughness from IRI to ride score, is not continuous for ride scores greater than 4.7. Since both of these equations are part of the ride quality model, these two equations may have contributed to the poor predictive capability of the ride quality models. It is recommended that these equations be reviewed.
- The PMIS alligator cracking model for pavement type ACP04 predicts the same percent cracking for any thickness of AC greater than 14 cm (5.5 inches). Since alligator cracking depends on the maximum strain at the bottom of the asphalt layer, which in turn depends on the thickness of asphalt layer, variation of thickness can affect the performance. The average thickness of AC used for the development of the alligator cracking models is not known. However, it can be presumed that the thicknesses of AC used for the development of alligator cracking models for pavement type ACP04 (and, for that matter, any other types) were greater than 14 cm

(5.5-inch) and less than some thicknesses. A variation in prediction can always be expected if the thickness of AC differs significantly from the average value of the AC used for the development of the model. The thicknesses of the asphalt layer in the five LTPP sections with pavement type ACP04 are 10.1-inch, 7.5-inch, 10.9-inch, 7.1-inch, and 10.0-inch. Therefore, this use of pavement type may have contributed to the poor predictive capability of the model. It is recommended that the thickness of the asphalt layer be incorporated in the PMIS models, especially for the alligator cracking models.

- It was found that the predictions of the alligator cracking model were closer to the observed alligator cracking plus longitudinal cracking in the wheel paths.
- The shallow and deep rutting models may be combined into one model that predicts the mean rut depth.
- PMIS does not provide a separate set of models to account for swelling subgrades.

FPS-19 Recommendations

The following points may be considered for the improvement of FPS-19:

- The value of the standard normal deviate used in the program for reliability level B may correspond to 85 percent reliability and not 90 percent reliability (which is displayed). It is recommended that this be reviewed.
- FPS-19 may further be evaluated using the intermediate results of the program. However, the program must be modified for this purpose.
- The pavement design type 5, “user-defined,” may be removed from the pavement design type options.
- The output data for pavement design type 7, “overlay design,” may be modified to exclude those feasible solutions which do not contain all the existing layers.
- Further research is recommended to improve the empirical model used by FPS-19 for the design of overlays in the second and subsequent performance periods.

CHAPTER 4: RECOMMENDED CHANGES TO PMIS

INTRODUCTION AND OBJECTIVES

The main objective of the 1727 study was to "evaluate and recommend improvements to pavement performance prediction models" for the Texas PMIS. The secondary objective was to strive towards more integration between network and project management levels such that the models used at each level do not contradict each other and result in a loss of confidence by users.

Figure 4.1 illustrates using separate network- and project-level design models to estimate the loss of serviceability over the life of the pavement; areas where the serviceability increases are planned treatments. This is basically the current situation within the TxDOT pavement management process; the network- and project-level models do not match.

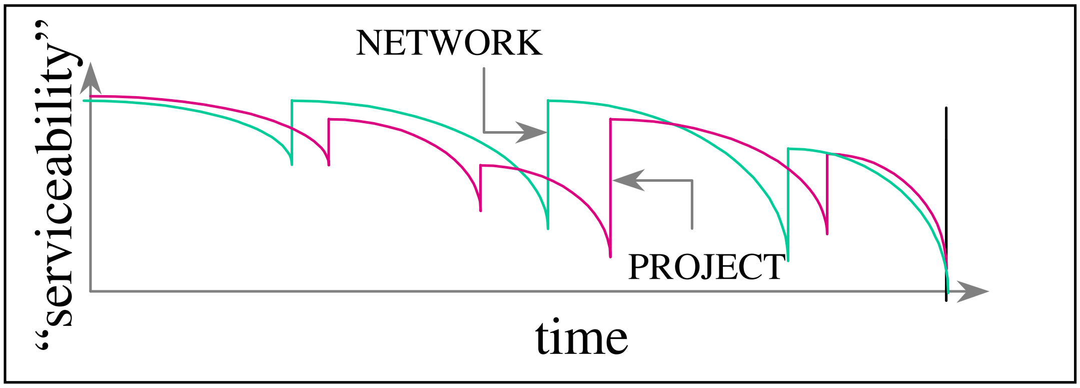


Figure 4.1 Comparison of Network and Project-Level Design Models

The ideal approach to correct this situation would be to create a single seamless system throughout all management levels. This would incorporate both the project and the network levels since these are, in concept, very similar: both involve the collection of condition data, the prediction of future condition, and the development of cost-effective designs and rehabilitation strategies. The major barriers to this integration are that it is not economically feasible to collect, and keep current, the detailed data necessary for project-level engineering analysis and design for *all* sections in the network. Furthermore, even preliminary design data is unlikely to be fully available on the entire TxDOT highway network. This precludes the ability to have the same projected conditions produced by the network-level analysis and project-level designs. Even if we use the same performance models for network-level planning/programming and project-level design, since different data will be used for the same sections at the two levels, the projected conditions would probably be different. In addition, if we have different levels of data, then different models may be more appropriate in each case. As a result, with the network and project levels remaining separate (with necessarily separate data and possibly models), the predictions and recommendations at each level will often be different. This does not mean that either prediction is wrong, per se, but rather that one is more accurate. All models have some level of inaccuracy involved; when condition is projected, it is only an estimate, and the projection includes some range of values within which the projected value is the mean value. It is expected that the error of the project-level model will be less than the error of the network-level model. Even though it also has some range of values within which the true value will lie, the project-level model is expected to be more accurate (have a lower error band and the mean value closer to the true value) than the network-level model. However, at the current time, the network-level and project-level models are based on different concepts. Thus, there is no way to ensure that the project-level projection is an improved version of the network-level projection.

Basic Pavement Management Information System Concepts

The PMIS is an automated system for storing, retrieving, analyzing, and reporting information designed to assist decision makers to make cost-effective decisions concerning the maintenance and rehabilitation of pavements.

PMIS can be used to assist decision makers at several levels of management. It is most commonly used at network level by the Pavement Design and Management Branch of the Design Division to assist in supporting planning and programming Maintenance and Rehabilitation activities. This includes how much funding is needed for a given analysis period and the impact of various funding levels and strategies on the pavement condition. Districts use PMIS at the project-selection level to assist in deciding which sections of the highway network need maintenance or rehabilitation and which ones should be repaired first when funds are limited. The highway sections selected in the project selection-level management are analyzed in detail at the project level. Project-level management is often referred to as pavement design because it includes the detailed engineering analysis required to determine the most cost-effective design and the maintenance treatment or rehabilitation strategy to be applied to the specific highway section.

Some of the main differences among network level, project selection-level, and project-level management are:

- the amount and type of data required,
- the level in the organization at which decisions are being made, and
- the type of decisions to be made.

Since data collection is expensive, minimum data is usually collected at the network level. However, this data collected at network level is not adequate for making project-level decisions because more complete and detailed data on individual highway sections must be collected; project-selection level may, or may not, require additional data collection. Decisions at the network level are related to the budget and funding processes. Project-selection level is related to the selection of candidate sections and prioritization of candidate highways sections. At project level, the decisions are concerned with the detailed assessment of the cause of deterioration and the selection of the most cost-effective maintenance, rehabilitation, or reconstruction strategy. Otherwise, the principles involved at the three levels should be the same.

Description of the Elements of TxDOT PMIS

The basic elements of the TxDOT PMIS currently include (12):

- an inventory of pavement sections,
- pavement condition data,
- needs estimate,
- prioritization of candidate highway sections for funding, and
- impact analysis of funding decisions on current and future pavement condition.

These are summarized here to facilitate the discussion of how they could be changed to more closely align the network-level, project-selection, and project-level activities within the TxDOT pavement management process.

Inventory

The network inventory stores basic information for pavement managers on the type and location of the pavements for which they are responsible. Since the entire length of the highway network is impossible to manage as a whole, the network is subdivided into sections. This process is called segmentation, and there are two general concepts in the TxDOT PMIS for making this segmentation. In the first concept, the highway network is divided into uniform size Data Collection Sections, which vary depending on the data being collected and the method used to collect it; for manual distress data, they are 0.8 km (0.5 m) in length. In the second concept, the highway network may be divided into Management Sections of Variable length, which are defined as sections of pavements, of similar structure and performance, that the engineer intends to maintain in a uniform manner. These may, or may not, be developed by the district personnel.

PMIS tries to minimize the data required for each data collection section to allow the software to function with a minimum amount of data. However, it allows additional data to be stored in the pavement layer database within PMIS. Other studies are being conducted to address the need for additional data and how to keep it current.

Pavement Condition Data

PMIS provides the capability of collecting and storing the following four types of pavement condition data:

- Visual distress data measures the surface defects such as patching, rutting (shallow and deep rutting), and cracking (block, alligator, longitudinal, and transverse cracking).
- Ride quality data measures the pavement roughness.
- Deflection data measures the overall pavement structural strength.
- Skid data measures pavement friction resistance.

The current analysis modules within PMIS primarily use the visual and ride quality data. These two data items are mandatory; they must be available for the PMIS to make projections of future conditions. The deflection and skid data are not currently used in PMIS, and they are not available for many of the sections. The serviceability index (SI) is calculated from the roughness data. The Distress Score (DS) is calculated from the distress data. The Condition Score (CS) is calculated from the SI and DS.

Needs Estimate

Once the highway network has been defined, basic data stored, and pavement condition data for each Data Collection Section have been collected, PMIS can be used to identify sections needing maintenance and rehabilitation. This is used to help pavement managers determine how much money they need to repair deficient pavement sections or prevent deterioration of non-deficient sections to provide a selected level of service.

PMIS currently uses a set of empirical prediction equations to project the future condition of each section in terms of each type of distress and roughness over the analysis period. These prediction equations are the primary focus of this study. PMIS then uses an array of decision trees to assign the required treatment level to each pavement segment based on the current condition and type pavement for the first year in the analysis period. The condition of each section identified as needing treatment is adjusted to reflect the impact of that treatment, and the condition is then again projected forward. The decision trees are again checked to see if a treatment is needed during the following year; if another treatment is needed, the condition is again modified. If no treatment is needed, the condition is projected forward without adjustment.

This is repeated for each year of the analysis period. It provides information about the future condition of the group of pavement analyzed, without treatments, and with the treatment level assigned by the decision trees.

Since network-level management is directed more at the level of treatment and the amount of funds required, the PMIS needs estimate program identifies which one of the following general treatment levels is needed for each highway section:

- needs nothing (NN),
- preventive maintenance (PM),
- light rehabilitation (LRhb),
- medium rehabilitation (Mrhb), and
- heavy rehabilitation/reconstruction (Hrhb).

The selection of the actual treatment must be made at project level since PMIS (and other network-level systems) does not contain sufficiently complete and accurate data to support project-level decisions. The use of general treatment levels in the needs analysis minimizes problems of pavement managers trying to use the PMIS for making project-level decisions when the program only provides network-level assistance.

Prioritization of Candidate Section

The PMIS needs estimate program identifies funds needed to provide the desired level of service through the maintenance and rehabilitation of the entire highway network without regard to available funds. However, the reality is that funds are limited, and there is not enough money available to repair all the highway sections in the network needing maintenance and rehabilitation treatments. PMIS prioritization of candidate highway sections is a systematic methodology developed to assist pavement managers in establishing priorities for selecting pavement sections to treat that will provide the best possible highway network condition for the available funds.

The current PMIS uses sequential annual ranking procedures to provide a multi-year prioritization based on an effectiveness to cost ratio. The effectiveness is defined as the sum of the areas under the distress (DS) and ride (SI) curves generated by any particular treatment minus any area that would be provided without the application of the treatment. At any point in time, the no-treatment change in condition and ride utility are projected over the planning period. The improvement in condition (effectiveness) is defined as the area between these curves. The life of the treatment is defined as either the time it takes for the after-treatment curve to intersect the no-treatment curve, or for the after-treatment curve to deteriorate and reach a user-designated minimum acceptable condition level, or failure.

Within PMIS, the following factors are involved in generating the ranking (cost-effectiveness ratio):

- the effectiveness (total area under both condition and ride curves),
- the life of treatment, and
- the annual equivalent treatment cost.

To provide a weighting factor for traffic, the calculated ratio is multiplied by $\log_{10}$ (VMT), where VMT is the vehicle miles traveled on the section.

This prioritization is considered a network-level analysis, or first cut at the sections that should be selected. It is not possible for PMIS to consider all of the factors that district personnel use in their selection of projects. As a result, it is understood that the districts will use the results of the prioritization as input to their project-selection process.

Impact Analysis

The PMIS impact analysis is used to show the effects of pavement decisions, policies, and other external factors on overall pavement condition and financial projections. Impact analysis helps pavement managers justify obligation authority or policy changes by providing information in a number of different ways regarding the expected effects on the current and future pavement conditions. Impact analysis is conducted by completing the prioritization for a specific set of criteria (funding level, amount allocated to preventive maintenance, failure criteria, etc.) and storing the results. Prioritization is again completed with a different set of criteria, and the results are stored. The results of these different scenarios are then used to compare the impacts of the changes. That information is then used to help develop the recommended program; this recommended program, or the program finally selected, is the one that should be used as input to the project-selection process.

Integrating Models

To move toward the integration across the spectrum of pavement management levels, we recommend that the curve projection parameters be stored with each individual data collection or management section. This effectively allows the performance curve projection parameters to be developed and stored from a network level, project-selection level, or project-level design equation. This one change in PMIS opens opportunities for continued future improvements to projection equations without requiring major changes to PMIS each time such an improvement is made. It allows development of custom projection equations for individual data collection or management sections for which more complete data is available while allowing the software to continue to operate with the simplistic empirical curves when the more complete data is not available. PMIS could function with any combination of data for any individual pavement section or any group of sections. This allows one district to use relatively accurate data in their analysis while another district that has less data can continue to function with the empirical models. In addition, by implementing an event-based data modification process in the data storage, curves that were previously used can be recalled at any time. This last approach would allow TxDOT to compare performance projected at different times during the life of the pavement to the latest projected performance.

This will require that the design systems, such as FPS-19, be modified so that they can provide the curve parameters that PMIS would need to store. At the current time, the design equations and PMIS do not even predict the same parameters. For instance, PMIS predicts cracking, rutting, roughness, etc. as a function of time for asphalt-surfaced pavements while FPS-19 predicts only serviceability index as a function of traffic loads. Thus, the design equations for asphalt-surfaced roads would need to be modified to project the same, or similar, condition measures as a function of time; or a routine would need to be developed which would extract that information from the information projected. This does not necessarily mean that design equations would need to produce all of the type of inputs needed for the PMIS; some empirical equations could still be used. However, all of them would need to be capable of providing the curve projection parameters required by PMIS.

PMIS in TxDOT

TxDOT has operated a network-level Pavement Management System since the early 1980s. The initial system was known as the Pavement Evaluation System (PES). In 1990, a Pavement Management Steering Committee was assembled to plan the next steps in improving and expanding PES. That committee recommended a two-phase approach to system development.

In Phase 1, the focus was on providing information on network pavement conditions and funding requirements to TxDOT's administrative level in Austin. This phase is now complete; TxDOT personnel regularly summarize PMIS data in annual reports showing condition trends and the impact of varying funding levels. The PMIS data are also used increasingly for maintenance and rehabilitation fund allocation.

Phase 2 was to focus on implementing PMIS at the district level, the goal being to provide sufficient information to assist with network-level decision support at the district level. Phase 2 implementation was delayed due to funding, and it cannot be achieved until key components are developed, such as the pavement layer database, use of management sections, and implementation of improved automation technology to facilitate database integration and map-based reporting.

Description of the Key Elements Within PMIS (12)

A summary of the key components used in TxDOT is included here to help the reader understand the recommendations provided in the next chapter (12).

Pavement Types

Within PMIS, the Texas highway network is broken into 10 pavement types as shown in table 4.1. This is essentially the only pavement layer information currently required by PMIS and available for all sections. Additional pavement layer data (including construction and rehabilitation dates) can be stored in PMIS, but that data is not available in the database for most sections. This information is explained in more detail in reference 12.

Table 4.1 PMIS Pavement Types (12)

Pavement Type		
Broad	Detail	Description
CRCP	1	Continuously Reinforced Concrete Pavement
JCP	2	Jointed Concrete Pavement - reinforced
	3	Jointed Concrete Pavement - unreinforced (plain)
ACP	4	Thick Asphalt Concrete Pavement (greater than 14.0 cm thick; [5.5"])
	5	Intermediate Asphalt Concrete Pavement (6.4-14.0 cm thick; [2.5-5.5"])
	6	Thin Asphalt Concrete Pavement (less than 6.4 cm thick; [2.5"])
	7	Composite Pavement (asphalt surfaced concrete pavement)
	8	Overlaid or Widened Old Concrete Pavement
	9	Overlaid or Widened Old Flexible Pavement
	10	Thin-surfaced Flexible Base Pavement (surface treatment or seal coat)

Condition Evaluation

In the fall of each year, the highway network is visually inspected. Pavement roughness and rutting measurements are made by TxDOT equipment. The basic distress data collection section is a 0.8 km (0.5 mi) in length. Currently, 100 percent of the interstate pavements and 50 percent of the remainder are inspected each fall; however, some districts inspect more frequently. PMIS uses the pavement distress types and rating methods shown in table 4.2 for continuously reinforced concrete pavements (CRCP), in table 4.3 for jointed concrete pavement (JCP), and in table 4.4 for asphalt concrete pavement (ACP). This information is explained in more detail in reference 12.

Table 4.2 PMIS CRCP Distress Types and Rating Methods (12)

CRCP Distress Type	Rating Method
Spalled Cracks	Total number (0 to 999)
Punchouts	Total number (0 to 999)
Asphalt Patches	Total number (0 to 999)
Concrete Patches	Total number (0 to 999)
Average Crack Spacing	Spacing (1 to 75), to the nearest 0.1 m (ft)

Table 4.3 PMIS JCP Distress Types and Rating Methods (12)

JCP Distress Type	Rating Method
Failed Joints and Transverse Cracks	Total number (0 to 999)
Failures	Total number (0 to 999)
Shattered (Failed) Slabs	Total number (0 to 999)
Slabs with Longitudinal Cracks	Total number (0 to 999)
Concrete Patches	Total number (0 to 999)
Apparent Joint Spacing	Spacing (15 to 75), to the nearest 0.1 m (ft)

Table 4.4 PMIS ACP Distress Types and Rating Methods (12)

ACP Distress Type	Rating Method
Shallow (6 to 12 mm [(¼" to ½"] depth) Rutting	Percent of wheelpath length (0 to 100)
Deep (13 to 25 mm [½" to 1"] depth) Rutting	Percent of wheelpath length (0 to 100)
Patching	Percent of lane area (0 to 100)
Failures	Total number (0 to 99)
Block Cracking	Percent of lane area (0 to 100)
Alligator Cracking	Percent of wheelpath length (0 to 100)
Longitudinal Cracking	Length per 100' station (0 to 999)
Transverse Cracking	Number per 100' station (0 to 99)
Raveling (optional)	None, low, medium, or high
Flushing (optional)	None, low, medium, or high

Pavement Score Calculation Process

A multiplicitive utility analysis approach is used to calculate the pavement score for every inspection section. Each distress value is converted into a utility value between 0 and 1 using a utility curve, with the exception of raveling, flushing, average crack spacing, and apparent joint spacing, which are not included in the score calculation. The basic shape of a pavement's utility curve is sigmoidal (S-shaped). This curve may be represented by the following equation:

$$U_i = 1 - \alpha e^{-\left(\frac{\rho}{L}\right)^{\beta}} \qquad (4.1)$$

where:

U = utility value;

i = a PMIS distress type (e.g., deep rutting or punchouts);

α = alpha, a horizontal asymptote factor that controls the maximum amount of utility that can be lost;

e = base of the natural logarithms ($\tilde{e}$ 2.71828...);
ρ = rho, a prolongation factor that controls how long the utility curve will last above a certain value;
L = level of distress (for distress types) or ride quality lost (for ride quality); and
β = beta, a slope factor that controls how steeply utility is lost in the middle of the curve.

The PMIS distress score is calculated from the pavement utility curves. PMIS uses the equations listed below, one for each broad pavement type (CRCP, JCP, and ACP) to calculate the distress score.

Equation for CRCP (Pavement Type = 1)

For CRCP sections, the following equation is used:

$$DS = 100 \text{ x } [U_{Spall} * U_{Punch} * U_{ACPat} * U_{PCPat}] \qquad (4.2)$$

where:

DS = Distress Score,
U = Utility Value,
Spall = Spalled Cracks,
Punch = Punchouts,
ACPat = Asphalt Patches, and
PCPat = Concrete Patches.

Equation for JCP (Pavement Type = 2-3)

For JCP sections, the following equation is used:

$$DS = 100 \text{ x } [U_{Flj} * U_{Fail} * U_{SS} * U_{Lng} * U_{PCPat}] \qquad (4.3)$$

where:

DS = Distress Score,
U = Utility Value,
Flj = Failed Joints and Cracks,
Fail = Failures,
SS = Shattered (Failed) Slabs,
Lng = Slabs With Longitudinal Cracking, and
PCPat = Concrete Patches.

Equation for ACP (Pavement Type = 4-10)

For ACP sections, the following equation is used:

$$DS = 100 \text{ x } [U_{SRut} *U_{Drut} *U_{Patch} *U_{Fail} *U_{Blk} *U_{Alg} *U_{Lng} *U_{Trn}] \tag{4.4}$$

where:

DS = Distress Score,
U = Utility Value,
SRut = Shallow Rutting,
DRut = Deep Rutting,
Patch = Patching,
Fail = Failures,
Blk = Block Cracking,
Alg = Alligator Cracking,
Lng = Longitudinal Cracking, and
Trn = Transverse Cracking.

The ride values are measured using automated equipment and reported as a serviceability index on a scale from 0 to 5, which is the user perception correlated to the roughness of the highway. The ride value is one of the main indicators of the need for pavement rehabilitation; it is the value predicted by the flexible pavement design process (FPS 19). Within PMIS, the ride values are converted into a Ride Utility score from 0 to 1.

To arrive at a final PMIS Condition Score for each segment of highway, the Distress Utility and Ride Utility scores are combined as shown below.

$$CS = 100 \text{ x } U_{DS} \text{ x } U_{RS} \tag{4.5}$$

where:

CS = Condition Score,
U = Utility Value,
DS = Distress Score, and
RS = Ride Score.

Pavement Deterioration Curves

Currently, within the PMIS program, the condition is projected over time to evaluate the consequences of applying the four different maintenance and rehabilitation treatments available within PMIS. The basic shape of the performance curves is sigmoidal (S-shaped). Most of the PMIS distress types have performance curve parameters based on an empirical analysis of past performance of similar pavement sections, which are listed in reference 12. Patching, raveling, flushing, average crack spacing, and apparent joint spacing do not currently have curve projection parameters. These curves can be represented by the following equation:

$$L_i = \alpha e^{-\left(\frac{\chi\varepsilon\sigma\rho}{AGE_i}\right)^{\beta}} \tag{4.6}$$

where:

L = level of distress (for distress types) or ride quality lost (for ride quality);
i = a PMIS distress type (e.g., deep rutting or punchouts) or ride score;

α = alpha, a horizontal asymptote factor that controls the maximum range of percentage distress growth or ride loss;

e = base of the natural logarithms ($\tilde{e}$ 2.71828...);

χ = chi, a traffic weighting factor that controls the effect of 18-k ESAL on performance;

ε = epsilon, a climate weighting factor that controls the effect of rainfall and freeze-thaw cycles on performance;

σ = sigma, a subgrade weighting support factor that controls the effect of subgrade strength on performance;

ρ = rho, a prolongation factor, in years, that controls how long the pavement will last before significant increases in distress occur;

AGE = pavement section age, in years; and

β = beta, a slope factor that controls how steeply condition is lost in the middle of the curve.

The χ, ε, and σ factors are curve modifiers used only in the performance curve equations.

Treatment Types and Cost

To provide the greatest possible use to TxDOT pavement managers, PMIS identifies the type of treatment (if any) that each pavement section requires based on the current level of distress and ride. However, these treatment types are broad categories because the network-level PMIS does not have the information necessary to propose a specific project-level pavement design.

Within PMIS, only four treatment levels are specified: a) preventive maintenance, b) light rehabilitation, c) medium rehabilitation, and d) heavy rehabilitation or reconstruction. These are general cost categories, and, within each, several specific treatment types are possible. For the network-level cost estimation, an average statewide treatment cost is assigned to each pavement type and treatment type. Examples of the typical specific treatments within each treatment type and the associated costs are shown in table 4.5.

Table 4.5 Examples of Proposed PMIS Treatment Types and Costs (12)

Pavement Type = 1-3

Treatment Type	Pavement Type		
	1 (CRCP)	2 (JCP, Reinforced)	3 (JCP, Unreinforced)
Preventive Maintenance (PM)	Crack (or Joint) Seal *$6,000 per lane mile* *$3,660 per lane kilometer*	Joint Seal *$6,000 per lane mile* *$3,660 per lane kilometer*	Joint Seal *$6,000 per lane mile* *$3,660 per lane kilometer*
Light Rehabilitation (LRhb)	CPR (Concrete Pavement Restoration) *$60,000 per lane mile* *$36,600 per lane kilometer*	CPR (Concrete Pavement Restoration) *$60,000 per lane mile* *$36,600 per lane kilometer*	CPR (Concrete Pavement Restoration) *$60,000 per lane mile* *$36,600 per lane kilometer*
Medium Rehabilitation (MRhb)	Patch and Asphalt Overlay *$125,000 per lane mile* *$76,250 per lane kilometer*	Patch and Asphalt Overlay *$125,000 per lane mile* *$76,250 per lane kilometer*	Patch and Asphalt Overlay *$125,000 per lane mile* *$76,250 per lane kilometer*
Heavy Rehabilitation or Reconstruction (HRhb)	Concrete Overlay *$400,000 per lane mile* *$244,000 per lane kilometer*	Concrete Overlay *$400,000 per lane mile* *$244,000 per lane kilometer*	Concrete Overlay *$400,000 per lane mile* *$244,000 per lane kilometer*

Note: Treatment costs for rigid pavements proposed by Design Division, Pavements Section

Table 4.5 Examples of Proposed PMIS Treatment Types and Costs (12) (continued)

Pavement Type = 4-6

Treatment Type	Pavement Type		
	4 (Thick Hot-Mix)	5 (Intermediate Hot-Mix)	6 (Thin Hot-Mix)
Preventive Maintenance (PM)	Crack Seal or Surface Seal *$10,000 per lane mile* *$6,100 per lane kilometer*	Crack Seal or Surface Seal *$10,000 per lane mile* *$6,100 per lane kilometer*	Crack Seal or Surface Seal *$8,000 per lane mile* *$4,880 lane kilometer*
Light Rehabilitation (LRhb)	Thin Asphalt Overlay *$35,000 per lane mile* *$21,350 lane kilometer*	Thin Asphalt Overlay *$35,000 per lane mile* *$21,350 lane kilometer*	Thin Asphalt Overlay *$35,000 per lane mile* *$21,350 per lane kilometer*
Medium Rehabilitation (MRhb)	Thick Asphalt Overlay *$75,000 per lane mile* *$45,750 lane kilometer*	Thick Asphalt Overlay *$75,000 per lane mile* *$45,750 per lane kilometer*	Mill and Asphalt Overlay *$60,000 per lane mile* *$36,600 per lane kilometer*
Heavy Rehabilitation or Reconstruction (HRhb)	Remove Asphalt Surface, Replace and Rework Base *$180,000 per lane mile* *$109,800 lane kilometer*	Remove Asphalt Surface, Replace and Rework Base *$180,000 per lane mile* *$109,800 per lane kilometer*	Reconstruct *$125,000 per lane mile* *$76,250 per lane kilometer*

Table 4.5 Examples of Proposed PMIS Treatment Types and Costs (12) (continued)

Pavement Type = 7-8

Treatment Type	Pavement Type	
	7 (Composite, Unwidened)	8 (Composite, Widened)
Preventive Maintenance (PM)	Crack Seal or Surface Seal *$11,000 per lane mile* *$6,710 per lane kilometer*	Crack Seal or Surface Seal *$11,000 per lane mile* *$6,710 per lane kilometer*
Light Rehabilitation (LRhb)	Thin Asphalt Overlay *$40,000 per lane mile* *$24,400 per lane kilometer*	Thin Asphalt Overlay *$40,000 per lane mile* *$24,400 per lane kilometer*
Medium Rehabilitation (MRhb)	Mill and Asphalt Overlay *$62,000 per lane mile* *$37,820 per lane kilometer*	Mill and Asphalt Overlay *$62,000 per lane mile* *$37,820 per lane kilometer*
Heavy Rehabilitation or Reconstruction (HRhb)	Remove Asphalt Surface, Replace and Repair Concrete Base *$175,000 per lane mile* *$106,750 per lane kilometer*	Remove Asphalt Surface, Replace and Repair Concrete Base *$175,000 per lane mile* *$106,750 per lane kilometer*

Table 4.5 Examples of Proposed PMIS Treatment Types and Costs (12) (continued)

Pavement Type = 9-10

Treatment Type	Pavement Type	
	9 (ACP, Overlaid and Widened)	10 (Seal Coat)
Preventive Maintenance (PM)	Crack Seal or Surface Seal *$11,000 per lane mile* *$6,710 per lane kilometer*	Surface Seal, No Patching *$6,000 per lane mile* *$3,660 per lane kilometer*
Light Rehabilitation (LRhb)	Thin Asphalt Overlay *$40,000 per lane mile* *$24,400 per lane kilometer*	Surface Seal, Light/Medium Patching *$11,000 per lane mile* *$6,710 per lane kilometer*
Medium Rehabilitation (MRhb)	Thick Asphalt Overlay *$62,000 per lane mile* *$37,820 per lane kilometer*	Surface Seal, Heavy Patching *$20,000 per lane mile* *$12,200 per lane kilometer*
Heavy Rehabilitation or Reconstruction (HRhb)	Remove Asphalt Surface, Replace and Rework Base *$175,000 per lane mile* *$106,750 per lane kilometer*	Rework Base and Surface Seal *$62,000 per lane mile* *$37,820 per lane kilometer*

Selection of Treatment Types

Each section is then analyzed to determine if a treatment is needed to provide the desired level of service. PMIS uses the following seven factors to identify if treatments are required:

- pavement type,
- distress ratings,
- ride score,
- average daily traffic (ADT) per lane,
- functional class,
- average county rainfall (in inches per year), and
- time since last surface (in years).

PMIS uses a series of decision tree statements to identify the treatment type needed for each pavement section. A decision tree statement might be:

ACP005 RECONST
TYPE OF TREATMENT: Heavy Rehabilitation or Reconstruction (HRhb).
CAUSE: ADT per lane greater than 5,000 and
Ride Score less than 2.5.

PMIS uses a reason code (ACP005 RECONST in the example) for each decision tree statement. The reason code helps the pavement manager identify why PMIS picked a particular treatment, which is important information since there are many combinations of factors that can call the same treatment. PMIS contains over 50 decision trees to assign the appropriate treatment to each pavement type.

Definition of Benefit

By applying a treatment, the pavement manager hopes to improve the overall condition (distress and ride quality) of the section, not just for the current fiscal year, but for many years to come. Each year that the condition of the newly treated section is better than its original untreated condition represents a benefit to the agency and its customers.

This concept of benefit can be represented as the area between two performance curves, as shown in figure 4.2. The bottom curve is the original, or untreated, condition of the section over time. This curve is based on the HRhb performance curve coefficients, which are the same as new construction coefficients. The upper curve represents the treated condition of the section over time. This curve is based on the performance curve coefficients for the treatment recommended in the needs estimate routine. The PMIS program uses a trapezoidal approximation to calculate the area between the two curves.

The benefit is defined as the sum of the distress and ride quality areas, each weighted equally, as shown in the equation below:

$$B = 2\left(\frac{W_D}{100}A_D + \frac{W_R}{100}A_R\right) \tag{4.7}$$

where:

B = Benefit of the “needed” treatment (from the needs estimate routine);

A_D = Area between the “before” and “after” distress score performance curves; and

A_R = Area between the “before ”and “after” ride score performance curves.

W_D and W_R are weighting factors for distress and ride areas, respectively. Currently, both are set to 50.

Cost-Effectiveness Ratio for Each Section

The purpose of computing the benefit and effective life for each section is to develop a measure which can be used to rank the sections in order of increasing effectiveness. The needs estimate program does not have such a measure because it does not consider available funding but considers only what the engineers think should be done. The optimization program, however, deals with the reality of limited funding, and, when funding is limited,

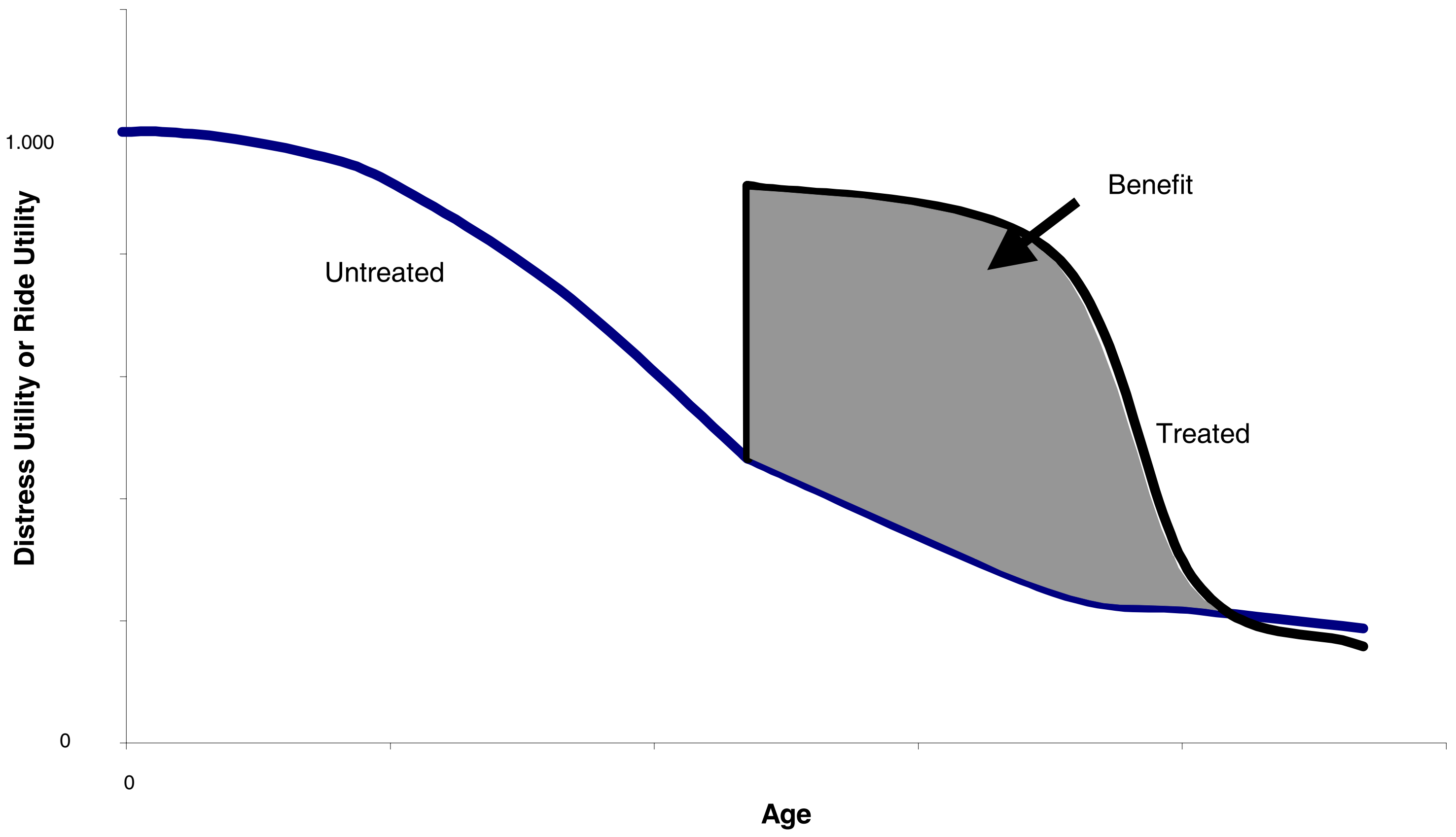


Figure 4.2 Definition of Benefit for PMIS Optimization Program (12)

the pavement manager needs a way to determine which sections will provide the greatest overall effectiveness.

To address this requirement, the PMIS optimization program defines a "cost-effectiveness ratio" for each section, as shown in the following equation:

$$CERatio = 10{,}000 * \left[\frac{LM * B}{EffLife * UACost} \right] * \log_{10} VMT \qquad (4.8)$$

where:

CERatio = Cost-Effectiveness Ratio;
LM = Lane Miles;
B = Benefit (distress and ride quality);
EffLife = Effective Life of the Needs Estimate treatment, in years;
UACost = Uniform Annual Cost of the Needs Estimate treatment, in dollars; and
VMT = Vehicle Miles Traveled.

The "10,000" term in the equation converts the cost-effectiveness ratio values into one- to four-digit integers (instead of small decimal values) which can be easily printed in a report.

As shown above, the cost-effectiveness ratio includes a weighting factor for vehicle miles traveled. In cases where identically effective sections are competing to be the last funded project, this factor gives preference to the section with the higher traffic.

The cost-effectiveness ratio annualizes cost over the effective life of the needs estimate treatment, as shown in the equation below:

$$UACost = TCost * \left[\frac{DRate(1 + DRate)^{EffLife}}{(1 + DRate)^{EffLife} - 1} \right] \qquad (4.9)$$

where:

UACost = Uniform Annual Cost of the Needs Estimate treatment, in dollars;
TCost = Treatment Cost (current or future) of the Needs Estimate treatment, in dollars;
DRate = Discount Rate, in percent per year; and
EffLife = Effective Life of the Needs Estimate treatment, in years.

The equation uses a discount rate, which is the expected return on investment if TxDOT chooses not to fund the needs estimate treatment.

RECOMMENDED CHANGES TO THE CURRENT SYSTEM

The following changes are recommended for the TxDOT PMIS.

Modify PMIS to Accept Individual Projection Parameters

The original PMIS should be modified to allow the prediction curve parameters to be stored for each individual data collection and/or management section. These would be a set of sigmoidal shape coefficients that will be described in detail later. The major modification to the program would be to change how the program selects the data used in projecting future condition. Currently, the pavement condition is projected using the sigmoidal equation. The program selects the projection parameters based on the surface type and functional classification using a routine currently located within the code. This code would need to be modified so that the program would only look for the projection parameters in the database with the section information. This requires minimal modification to the existing PMIS concept, but it will substantially improve the performance predictions.

The program could then use the best available projection parameters. If only the basic required data are available, then the current empirical models could be used to generate those sigmoidal parameters. If during project selection additional pavement layer data are collected and entered, mechanistic-empirical equations could be used to generate more accurate sigmoidal parameters. When the final design is completed, the design program could then be used to generate even more accurate parameters. If appropriate data are collected during the construction, the design projection parameters could be updated based on the as-built data. After being subjected to traffic and environmental damage for a period of time, the projection parameters could be adjusted to reflect the impact of that damage. All of this is permitted because these projection parameters are developed outside the basic program. The program would not care where the parameters came from; it would only care that the appropriate projection parameters are present in a database that it accesses.

The current empirical models would be retained, but they would be packaged differently. They would be programmed to provide the required projection parameters for a pavement section, and those parameters could then be stored in the database for that section. Additional mechanistic-empirical models could also be developed and packaged as a part of the condition projection process. When adequate data are available, these mechanistic-empirical models could be used to develop the projection parameters, rather than the empirical models. They also would be outside the PMIS analysis programs, and they would produce the projection parameters to be stored with the section data. This module would also allow sigmoidal curve parameters to be entered from an outside design program; this would allow the user to enter the sigmoidal curve parameters from any equation that would produce the appropriate parameters. This approach would require a new user interface that would be capable of advising the user of the best approach to use in determining the projection parameters based on the data stored in the database at the time of the analysis and allowing the parameters to be entered from design equations. This would also allow the curve parameters to be updated based on as-built or other additional data for a section with existing projection parameters.

Convert To Event-Based Structure

Currently, when data is modified, the existing information is replaced. To be able to track how changes have occurred and to facilitate changes to existing data, each change to selected data would be considered an event. The data for the latest event would be marked as the current event, and all analysis would be based on the data in this current data set. The data which had been current prior to this last event would be retained. The data could be kept in the same database, but it would be marked as inactive, with a date-time notation of when it was marked inactive. It could alternatively be migrated to a set of data tables containing only inactive data. At any time, the history of changes could be prepared by retracing the changes from active to inactive. This way, prior events could be changed or added, and subsequent changes could be appropriately adjusted.

This would allow parameter sets that were previously used to be kept for analysis. For instance, the curve parameters from the initial project-level design analysis could be stored as the best available prediction. After PMIS condition surveys have been conducted, a regression curve could be generated on this data and this 'actual' curve compared with the original design. When a treatment is applied, the condition of this 'actual' curve could be adjusted to project the condition based on a improved condition. After another inspection, the projected condition could again be adjusted to reflect the observed condition. By retaining each set of model parameters in the database, feedback of projected condition versus observed condition could be constructed from the inactive data. This would allow better adjustments of the empirical performance curves; and it would assist in the calibration of mechanistic-empirical performance equations.

Modify PMIS to Accept Additional Projection Parameters

The current projection technique would also need to be modified to accept two additional parameters to improve the projection capabilities of the sigmoidal curve. The current projection curves use the following equation:

$$L_i = \alpha e^{-\left(\frac{\chi\varepsilon\sigma\rho}{AGE_i}\right)^{\beta}} \tag{4.10}$$

where:

L = level of distress (for distress types) or ride quality lost (for ride quality);

i = a PMIS distress type (e.g., deep rutting or punchouts) or ride score;

α = alpha, a horizontal asymptote factor that controls the maximum range of percentage distress growth or ride loss;

e = base of the natural logarithms (e˜ 2.71828...);

χ = chi, a traffic weighting factor that controls the effect of 18-k ESAL on performance;

ε = epsilon, a climate weighting factor that controls the effect of rainfall and freeze-thaw cycles on performance;

σ = sigma, a subgrade weighting support factor that controls the effect of subgrade strength on performance;

ρ = rho, a prolongation factor, in years, that controls how long the pavement will last before significant increases in distress occur;

AGE = pavement section age, in years; and

β = beta, a slope factor that controls how steeply condition is lost in the middle of the curve.

The χ, ε, and σ curve modifiers would not be needed within the basic PMIS program in the proposed approach; however, they could still be used in the empirical development of the projection parameters.

To account for situations where an initial amount of damage is always present, such as the crack spacing in CRCP pavements, we recommend adding a parameter to account for some initial level of damage. To account for the time it takes for some types of distress to initiate, such as alligator cracking in asphalt pavements, we recommend adding a parameter to the distress to remain at zero for some period of time after construction. This would result in the following modified sigmoidal (S-shaped) curve equation with five shape coefficients:

$$L_i = \gamma + \alpha e^{-\left(\frac{\chi\rho}{AGE_i - \delta}\right)^{\beta}} \qquad (4.11)$$

where:

α = alpha, a horizontal asymptote factor that controls the maximum range of percentage distress growth or ride loss;
e = base of the natural logarithms (e˜ 2.71828...);
δ = delta, horizontal shift factor controlling the age at which the first sign of distress appears, for example, on a thin overlay, shallow rutting might not appear until year 3;
γ = gamma, vertical shift factor giving the initial level of the distress if this is non-zero, for instance there will always be an average crack spacing, even in a new CRCP;
ρ = rho, a prolongation factor, in years, that controls how long the pavement will last before significant increases in distress occur;
χ = chi, a modifying factor for rho that accounts for a change in projection based on observed performance;
β = beta, a slope factor that controls how steeply condition is lost in the middle of the curve; and
AGE = pavement section age, in years.

Figure 4-3 illustrates these five parameters.

Regression Module to Accept Non-Sigmoidal Design Projections

Initially, a module would be needed that could take projected conditions from a design program that does not generate the needed sigmoidal curve parameters and generate the needed parameters, probably using a least squares analysis. Design data points generated using the original design models would be entered, and after the regression is completed, the calculated curve coefficients would be stored. This allows the PMIS to use input from any design approach that could project the condition of the pavement over time.

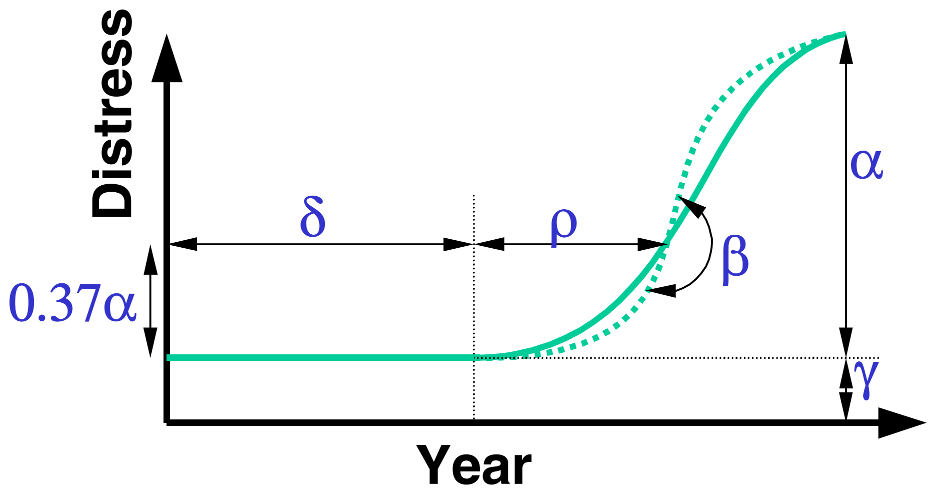


Figure 4.3. Shape Coefficients Used by Pilot Program

Regression Module to Adjust Individual Projections

A regression approach would be used to adjust the projection parameters when inspection data are entered. Those that are performing more poorly than projected by the design equation would then have the projected condition adjusted to show a reduced expected life, and the reverse for those performing better than projected.

The projection techniques within the software are modified to adjust the predicted performance based on observed performance. At the current time, the projection curves are shifted to make them pass through the observed condition. This somewhat individualizes the curves, but it can lead to distinctly different projected conditions among different years. It is proposed that, once the data for a section contained a construction date for the current surface, then a weighted regression or Bayesian approach would be used to adjust the projected condition. Instead of just passing the curve through the observed point, a conditional probability, or Bayesian, approach would be used. Thus, if several projected conditions were lower than the initial projections, the overall projections would be adjusted. However, if the observed conditions vary both lower and higher than the projected, the projected curve would not significantly vary from the initial. This would individualize the projection curves for each data collection or management section. Again, the calculations would be done outside the projection process when the condition data are entered, and the resulting values would be stored in the database for the affected sections.

Recognize the Project Selection Level

Ideally, the network-level pavement management elements should identify funding needs and prioritize sections needing work. They should show the impact of different funding strategies to justify fund requests. However, in an agency such as TxDOT, the funds are allocated among a series of different funding categories before they are allocated to pavement segments. We can think of this as a strategic level, which is normally completed at the departmental level, followed by an intermediate, or tactical, level at the district level where segments are selected. The actual design of treatments normally is completed at the district or area office level. To accommodate this type of management process, it is suggested that a third, intermediate management level needs to be identified in the process.

This intermediate level would operate between the network- and project-level analysis to assist with project selection and develop more accurate funding estimates. Some of the problems encountered included inadequate time to develop reasonable cost estimates of the segments recommended for funding. As the pavement segment recommended for repair is converted into a project that includes much other work, the funds are often inadequate if the fund recommendations are based only on the pavement repair. In addition, in some cases, treatments are recommended without sufficient investigation, and when the treatments are applied, change orders have to be made or a structurally inadequate treatment will be applied to keep within the fund limits.

The purpose of this intermediate level is to provide support at this level. This was identified as a project selection level in reference 3, and would require more data than normally collected at network level but less data than needed for full project-level analysis and design. It can be considered network-level analysis at the district level. The number of segments that would be included should be much fewer than all those in the network but could include more than what will finally be funded.

After completing the normal network-level analysis, those segments that are obviously not candidates for maintenance, rehabilitation, or reconstruction in the analysis period could be removed from further analysis. For those segments for which the appropriate levels of treatment and funding needed are accurate enough, the treatment and pavement repair costs can be set for the analysis period. However, additional funding for other activities could be added to the final cost estimate. The remainder of the segments can then be identified for additional data collection and analysis; this could include coring and deflection testing for selected asphalt pavement segments to determine if they can be repaired by patching and a seal coat or whether a structural improvement is needed. Others might need additional soil tests or field visits to determine if some unique problem, such as swelling soil, would require special repairs. It might include surveys of the drainage facilities or other cost items to determine if major corrections are needed that will lead to additional costs being added to the project. Once the segments are selected, the final design, plans, and specifications can be completed.

Hardware and Software Architecture

The Information Systems Division (ISD) of TxDOT has adopted an architecture for hardware and software use in TxDOT. The following recommendations are based on using that architecture.

The current PMIS software and data are on the TxDOT mainframe computer system. The data are stored in ADABAS, and the analysis routines are written in SAS. Data for an individual district can be moved to a microcomputer database with a significant amount of effort, but not the analysis tools. A series of standard reports are provided, but they are difficult to change.

To make the PMIS software useable at the project-selection level for the engineers in the districts and area offices, a user-friendly interface to the analysis tools and data is needed. It is recommended that the PMIS data be stored in a relational database such as SYBASE or ORACLE to allow client-server access to the data at district and area office levels. The analysis programs should be written in an object-oriented language compatible with

Windows NT, or a web interface, and the data should be kept in an event-based structure. The analysis package should include a group of standard reports, similar to those currently available. However, it should also provide a custom report generator that would allow the districts and area offices to generate their own reports. All data analysis results should be stored in a data file so that they could be accessed with both the standard and custom reporting procedures. The software should provide a data export capability so that the districts and area offices can export data to Excel or Access to generate tables and graphs as needed.

Moving To Management Sections

The PMIS development should focus on project selection-level support at selected districts. Currently, the data are reported for 0.8 km (0.5 mi) inspection sections. It is thought that the half-mile sections are adequate for administrative-level condition estimation and maintenance needs estimation, but they are very restrictive in the main function of district operations, that of project selection and prioritization. Projects can be of any length and frequently contain many half-mile inspection sections.

Three options are available for selecting candidate management section limits. Firstly, the default control section limits could be used. Secondly, the district pavement engineer could supply the limits for each proposed section. In the questionnaire responses, most of the districts replied that they could supply potential section limits. A third possibility would be to let the computer review the contiguous 0.5 mile data and automatically decide on section limits based on variations in the ride and condition scores. The cumulative difference method is a reasonable approach for this; this method is embedded within the MODULUS system to assist is processing project-level deflection data. TxDOT personnel are already familiar with it through that association. In the 1420 study, prototype software was assembled and tested on almost 50 miles of PMIS data from the Laredo District.

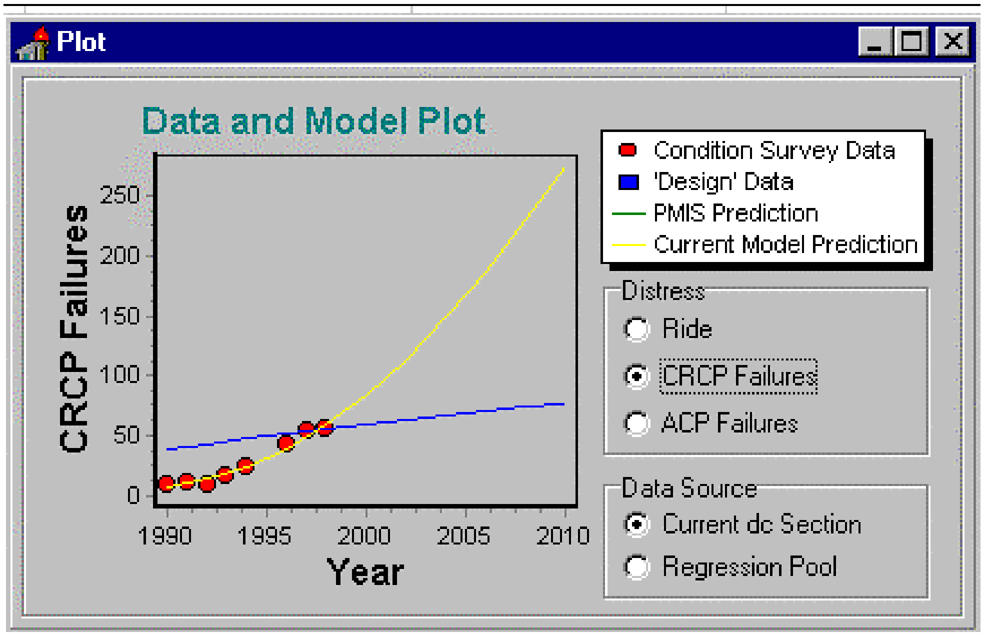
PILOT COMPUTER PROGRAM

To demonstrate the model customization concept, a pilot computer program was developed. The program allows users to connect to the actual PMIS database and, thereafter, to use filtering capabilities to generate a number of models by regression of existing PMIS condition data. It also allows users to enter their own data points from other sources and generate sigmoidal models based on that data.

Figure 4.4 shows a screen capture from the program. In this example, condition survey data from the Fort Worth District was extracted from PMIS and used in a regression analysis to develop a model. The lower, straight line in the figure shows the current PMIS prediction model for CRCP failures (punchouts plus patches). In PMIS, the age of the section is not known, so the program always adjusts the prediction curve to pass through the latest data point. Since the model used is derived from thousands of data points collected from pavement sections across the state over a 20-year period, it predicts the behavior of an average CRCP section based on the observed condition most recently measured during an annual distress survey.

The figure shows that this particular maintenance section is experiencing failure development at a higher rate than average. This pilot program demonstrates that improving the performance curve to better fit all of the observed data and the original date of construction will provide a better fit of the observed data. We believe that it will also provide a better prediction of future condition.

This approach makes each model highly specific to each section. Predicted values become dependent on actual conditions at the site. This is accomplished by using modified sigmoidal (S-shaped) curves. The curves use the five shape coefficients, α, β, ρ, δ, and γ, described above in conjunction with figure 4.3.



Distress
○ Ride
● CRCP Failures
○ ACP Failures

Data Source
● Current dc Section
○ Regression Pool

Figure 4.4. Comparison of PMIS and Pilot Program Models Using Data from the Fort Worth District.

CHAPTER 5: SUMMARY AND RECOMMENDATIONS

SUMMARY

This report has discussed the reasons for integrating network- and project-level performance prediction models for PMIS used by TxDOT. The need to improve the confidence of the users in both models that was discussed in Report 1727-1. The move toward performance-based specifications was included as another reason for integrating the models in this report. The evaluation of asphalt models was described in some detail. Some of the main conclusions follow. Recommendations for changing PMIS to accommodate the move toward integrating network- and project-level performance projection models are provided.

PMIS Models

The PMIS models are not predicting the ride quality values observed at the LTPP sites, although models for some pavement types are giving better predictions than the others. Table 3.30 indicates that the PMIS model over-predicts the roughness about 60 percent of the time and under-predicts the roughness about 40 percent of the time. However, this varies with surface type. For surface type ACP04 the PMIS model over-predicted roughness in about 53 percent of the cases. The PMIS model under-predicted roughness in about 83 percent of the cases for surface type ACP05. However, the PMIS model over-predicted roughness in about 87 percent of the cases for surface ACP06. Thus, no obvious overall trend of over- or under-prediction was found; rather, it was concluded that the model suffers from a lack of precision.

The predictions by the PMIS alligator cracking models are closer to the observed data if longitudinal cracking in the wheel paths is considered as fatigue cracking and added to alligator cracking data. Even then the alligator cracking models for pavement types ACP04, ACP05, and ACP06 are not predicting the values observed at the LTPP sites. Table 3.42 indicates that when the longitudinal cracking observed in the SHRP distress surveys is added to the observed alligator cracking, the PMIS model over-predicts the cracking by about 62 percent of the time and under-predicts the cracking about 38 percent of the time. This prediction varies with surface type. For surface type ACP04 the PMIS model over-predicts cracking about 68 percent of the time. For surface type ACP05 the PMIS model over-predicts 100 percent of the time. For surface type ACP06 the PMIS model under-predicts 56 percent of the time. Thus, while the PMIS model generally over-predicts cracking, this is not true for all surface types. In general, it was concluded that the model suffers from a lack of precision.

The shallow rutting and deep rutting PMIS models are generally over-predicting the values observed at the LTPP sites. The PMIS model predicted rutting on several sites that had no observed rutting.

All of these models should be modified to improve precision. However, it will not be possible to achieve much improvement until pavement layer data is available for use in developing new models and for use by the prediction models used in PMIS.

FPS-19 Model

FPS-19 was more difficult to evaluate because of the additional data requirements such as initial SI and ESAL values that were not always available in the data. No obvious trend of over- or under-prediction was found; however, it was found that FPS-19 is not accurately predicting performance as observed at the LTPP sites. It can be concluded that the FPS-19 equation also suffers from a general lack of precision.

Recommended Changes

A brief summary of PMS concepts and how TxDOT PMIS addresses them was provided for readers not intimately familiar with the current program, since the recommendations are meaningless without this knowledge. The key change is storing individual performance equation parameters for each individual section. The second most important change is to allow the use of two additional parameters in the sigmoidal performance equations. A method to accept non-sigmoidal projections from current design equations would be needed. A better method to adjust the projected performance based on observed performance is recommended. It is suggested that TxDOT recognize the network-level activities used at district level as a special emphasis, which was called project-selection level in the recommended changes. Some changes in hardware and software would be needed. Finally, it is believed that management sections should be emphasized.

RECOMMENDED APPROACH TO MODIFYING THE CURRENT SYSTEM

We understand that the Information Systems Division will need to be involved in the approval of any final program to be used for PMIS in TxDOT. We recommend developing a proof of concept program that would double as the final physical design. It would be programmed in a simple Windows® compatible language, such as Visual Basic, which would allow the concepts applied to be easily discerned by those programming the final version in a more robust and flexible language. An object-oriented approach would be used in this proof of concept programming effort. For this proof of concept program, the data would be stored in a relatively simple database manager such as Access. The data structure would be based on an event-based concept, and it would exercise the storage of performance parameters for individual sections. This exercise would be used to finalize the decisions about storing and updating the projection parameters for every data collection section versus some approach that would use management sections.

To keep this effort reasonable, we recommend that this effort be made for a project selection-level component to be installed in one or two districts for a trial period. At the end of that period, the final concept documents would be provided along with the proof of concept program as the final physical design. These documents could then be used as the basis for the full programming effort. Pavement layer data, including dates of construction, should be stored in the PMIS database or a database that PMIS can access. FPS-19 should be modified to predict cracking and rutting. If FPS-19 will no longer be used, then a design procedure that will predict cracking, rutting, and roughness should be adopted. These models should be calibrated to Texas data.

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APPENDIX A

SUMMARY DATA SHEETS

SUMMARY DATA SHEET

LOCATION

SHRP ID 1047-1

STATE		DISTRICT				COUNTY				LATITUDE ,	ELEVATION	ROUTE	FUNCTIONAL
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN	LONGITUDE	(FT)	NO	CLASS
Texas	48	Amerillo	4	4	4	Carson	65	33	33	35.21,101.18	3301	40	1

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet Freeze	253.1	22.3	56	20		

INVENTORY

SECTION	LANE		INNER PAVED SHOULDER		OUTER PAVED SHOULDER		PAVEMENT	SUB-SURFACE	CONSTRUCTION	TRAFFIC OPEN
LENGTH	NOS	WIDTH	SURFACE TYPE	WIDTH	SURFACE TYPE	WIDTH	TYPE	DRAINAGE	DATE	DATE
FT		FT		FT		FT				
500	2		AC	4	AC	10	1	None	01-Sep-70	01-Jul-71

PAVEMENT LAYERS						
LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine-Grained Soils: Clay with Sand				
2	TS	Subbase: Lime-Treated Soil	14.40		6.00	3.0
3	GB	Base: Crushed Stone	15.30		12.00	
4	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	7.40	7.42		
5	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	0.80	0.74		
6	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	0.70	0.72	9.00	
7	AC	Interlayer	0.10	0.10		
8	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	1.10	1.05	1.00	
	AC	**Total AC Thickness**	**10.10**	**10.01**	**10.00**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
5420		5,993,000

PAVEMENT CONDITION

FATIGUE CRACKING						
SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
11-Jun-91	20.0		5.974	0.00	1.12	1.12
19-May-93	21.9		6.671	0.00	5.41	5.41
10-Aug-95	24.1		7.473	0.00	5.41	5.41

RUTTING							
SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ

RIDE QUALITY						
SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
29-Oct-90	19.3		5.760	2.08	3.13	2.91
13-Nov-91	20.4		6.127	2.09	3.12	2.90
7-May-93	21.9		6.659	2.16	3.05	2.85
22-Nov-94	23.4		7.216	1.58	3.65	3.31

BACK-CALCULATED MODULI

FWD TEST	TEST	SUBGRADE		SUBBASE		BASE		HMAC		TEMPERATURE		AVERAGE
DATE	LINE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	SURFACE	AIR	ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
7-Aug-89	BWP	19.0	2.9			23.5	8.2	546.0	158.0	67.2	64.9	1.2

SUMMARY SUMMARY DATA SHEET

LOCATION

SHRP ID 1050-1

STATE		DISTRICT				COUNTY				LATITUDE , LONGITUDE	ELEVATION (FT)	ROUTE NO	FUNCTIONAL CLASS
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN				
Texas	48	Bryan	17	17	17	Grimes	185	94	94	30.35, 95.92	378	105	6

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	27.2	38	90	6		

INVENTORY

SECTION LENGTH	LANE NOS	LANE WIDTH	INNER PAVED SHOULDER SURFACE TYPE	INNER PAVED SHOULDER WIDTH	OUTER PAVED SHOULDER SURFACE TYPE	OUTER PAVED SHOULDER WIDTH	PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
FT		FT		FT		FT				
500	1	12			AC	8	1	None	01-Jun-83	01-Jul-85

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine Grained Soils: Lean Clay with Sand				
2	TS	Subbase: Lime-Treated Soil	6.50		8.00	4.0
3	GB	Base: Crushed Stone	9.60		10.01	
4	AC	Seal Coat: Chip Seal	0.80	0.79	0.80	
5	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	1.00	0.97	1.00	
	AC	**Total AC Thickness**	**1.80**	**1.75**	**1.80**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
3600		651,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
15-Nov-90	5.378		0.372	10.01	10.01	10.01
28-May-91	5.91		0.383	2.80	15.89	15.89
13-Jul-93	8.0		0.424	19.27	28.95	28.95
24-Jul-95	10.1		0.463	56.40	61.62	61.62

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
16-Mar-90	4.7		0.357	1.21	4.12	3.65
4-Apr-91	5.8		0.380	1.35	3.94	3.52
3-Nov-92	7.3		0.411	1.39	3.89	3.49
3-Nov-94	9.3		0.449	1.74	3.49	3.19

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
15-Nov-90	5.4		0.372	0.00	0.00	0.122	0.005
28-May-91	5.9		0.383	0.00	0.00	0.156	0.007
13-Jul-93	8.0		0.424	0.00	0.00	0.231	0.010

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE MEAN	SUBGRADE STD. DEV.	SUBBASE MEAN	SUBBASE STD. DEV.	BASE MEAN	BASE STD. DEV.	HMAC MEAN	HMAC STD. DEV.	TEMPERATURE SURFACE	TEMPERATURE AIR	AVERAGE ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
7-Jun-89	BWP	22.7	3.3			68.0	38.7	420.0	0.0	85.3	82.6	4.7

SUMMARY SUMMARY DATA SHEET

LOCATION

SHRP ID 1060-1

STATE		DISTRICT				COUNTY				LATITUDE , LONGITUDE	ELEVATION (FT)	ROUTE NO	FUNCTIONAL CLASS
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN				
Texas	48	Corpus Christi	16	16	16	Refugio	391	196	196	28.51, 97.06	78	77	2

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	6.2	33.1	96	5		

INVENTORY

SECTION LENGTH	LANE		INNER PAVED SHOULDER		OUTER PAVED SHOULDER		PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
	NOS	WIDTH	SURFACE TYPE	WIDTH	SURFACE TYPE	WIDTH				
FT		FT		FT		FT				
500	2	12	AC	4	AC	10	1	None	01-Mar-86	01-Mar-86

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Coarse Grained Soil: Silty Sand				
2	TS	Subbase: Lime-Treated Soil	6.00		8.00	1.5
3	GB	Base: Crushed Stone	12.30		12.00	1.0
4	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	5.80	5.76	5.70	
5	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	1.70	1.69	1.30	
	AC	**Total AC Thickness**	**7.50**	**7.45**	**7.00**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
7800		1,822,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
10-Apr-91	5.112		0.790	0.00	0.00	0.00
26-Mar-92	6.074		0.896	0.00	1.21	1.21
31-Mar-93	7.088		1.008	0.00	2.30	2.30
11-Oct-94	8.619		1.105	0.00	1.41	1.41
15-Mar-95	9.0		1.132	0.00	0.00	0.00
20-Mar-95	9.058		1.132	0.00	1.41	1.41
14-Jun-95	9.293		1.147	0.00	0.79	0.79

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
10-Apr-91	5.112		0.790	0.00	0.00	0.129	0.007
26-Mar-92	6.071		0.896	0.00	0.00	0.131	0.006

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
3-Apr-90	4.1		0.691	1.55	3.69	3.34
22-Apr-91	5.1		0.794	1.27	4.04	3.60
23-Jul-93	7.4		1.028	1.32	3.98	3.55
15-Dec-93	7.8		1.053	1.36	3.92	3.51
22-Apr-94	8.1		1.075	1.37	3.92	3.51
14-Jul-94	8.4		1.089	1.35	3.93	3.52
25-Oct-94	8.7		1.107	1.40	3.87	3.47
19-Jan-95	8.9		1.122	1.43	3.84	3.45
20-Apr-95	9.1		1.138	1.43	3.83	3.45
27-Jun-95	9.3		1.150	1.43	3.84	3.45

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE		SUBBASE		BASE		HMAC		TEMPERATURE		AVERAGE ERROR
		MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	SURFACE	AIR	
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
5-Mar-90	BWP	16.7	1.5			375.5	173.0	1308.0	142.0	68.7	71.1	1.1

SUMMARY DATA SHEET

LOCATION

SHRP ID 1068-1

STATE		DISTRICT				COUNTY				LATITUDE , LONGITUDE	ELEVATION (FT)	ROUTE NO	FUNCTIONAL CLASS
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN				
Texas	48	Paris	1	1	1	Lamar	277	139	139	33.51, 95.59	445	19	2

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	96.8	50.2	78	4		

INVENTORY

SECTION LENGTH	LANE		INNER PAVED SHOULDER		OUTER PAVED SHOULDER		PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
	NOS	WIDTH	SURFACE TYPE	WIDTH	SURFACE TYPE	WIDTH				
FT		FT		FT		FT				
500	2	12	AC	4	AC	10	1	None	01-Jun-85	01-Jun-87

PAVEMENT LAYERS						
LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine Grained Soil: Sandy Lean Clay				
2	TS	Subbase: Lime-Treated Soil	8.00		8.00	6.0
3	GB	Base: Crushed Stone	6.00	10.01	6.00	
4	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	7.80	7.72	7.00	
5	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	3.10	3.10	3.00	
	AC	**Total AC Thickness**	**10.90**	**10.81**	**10.00**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
5500		1,666,000

PAVEMENT CONDITION

FATIGUE CRACKING						
SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
26-Jun-91	4.1		0.413	0.00	3.71	3.71
13-Aug-93	6.2		0.522	12.27	21.72	21.72
27-Jan-95	7.7		0.604	17.55	44.45	44.45
13-Apr-95	7.9		0.617	15.50	44.37	44.37
8-Jun-95	8.0		0.626	15.50	44.37	44.37
21-Jul-95	8.1		0.633	16.25	45.12	45.12

RUTTING							
SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
26-Jun-91	4.071		0.413	0.00	0.00	0.095	0.003

RIDE QUALITY						
SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
25-Apr-90	2.9		0.356	1.10	4.27	3.75
23-Oct-91	4.4		0.429	1.13	4.24	3.73
26-May-93	6.0		0.510	1.22	4.11	3.64
20-Dec-93	6.6		0.541	1.23	4.09	3.63
20-Apr-94	6.9		0.560	1.41	3.87	3.47
12-Jul-94	7.1		0.573	1.21	4.12	3.65
27-Oct-94	7.4		0.590	1.19	4.15	3.67
16-Jan-95	7.6		0.602	1.26	4.05	3.60
19-Apr-95	7.9		0.618	1.22	4.10	3.64
22-Jun-95	8.1		0.628	1.19	4.16	3.68

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE		SUBBASE		BASE		HMAC		TEMPERATURE		AVERAGE ERROR
		MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	SURFACE	AIR	
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
23-Aug-89	BWP	18.9	1.7			37.7	25.0	362.0	78.0	88.1	79.9	0.8

SUMMARY DATA SHEET

LOCATION

SHRP ID 1077-1

STATE		DISTRICT				COUNTY				LATITUDE , LONGITUDE	ELEVATION (FT)	ROUTE NO	FUNCTIONAL CLASS
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN				
Texas	48	Childress	25	25	25	Hall	191	97	97	34.54,100.44	1835	287	2

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet Freeze	181.9	22.8	85	9		

INVENTORY

SECTION LENGTH	LANE		INNER PAVED SHOULDER		OUTER PAVED SHOULDER		PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
	NOS	WIDTH	SURFACE TYPE	WIDTH	SURFACE TYPE	WIDTH				
FT		FT		FT		FT				
500	2	12	PCC	4	PCC	10	1	None	01-Jan-82	01-Jan-82

PAVEMENT LAYERS						
LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine Grained Soil: Sandy Silt				
2	GB	Base: Crushed Stone	10.40		10.01	
3	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	3.70	3.71	4.50	
4	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	1.40	1.38	1.30	
	AC	**Total AC Thickness**	**5.10**	**5.08**	**5.80**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
4800		4,165,000

PAVEMENT CONDITION

FATIGUE CRACKING						
SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
7-Nov-91	9.9		1.729	0.00	0.00	0.00
20-May-93	11.4		1.923	0.00	12.37	12.37
24-Oct-94	12.8		2.142	0.97	15.31	15.31
20-Apr-95	13.3		2.228	0.00	18.08	18.08
22-Jun-95	13.5		2.260	0.00	18.08	18.08
11-Aug-95	13.6		2.286	0.00	18.08	18.08
25-Jun-96	14.5		2.460	0.00	18.08	18.08

RUTTING							
SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
25-Jun-96	14.5		2.460	62.50	0.00	0.605	0.037

RIDE QUALITY						
SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
31-Oct-90	8.8		1.622	1.19	4.15	3.67
8-Nov-91	9.9		1.729	1.25	4.07	3.62
5-May-93	11.3		1.917	1.25	4.07	3.61
6-Jan-94	12.0		2.013	1.08	4.31	3.78
19-Apr-94	12.3		2.059	1.20	4.14	3.66
8-Jul-94	12.5		2.094	1.27	4.05	3.60
14-Oct-94	12.8		2.138	1.32	3.97	3.55
11-Jan-95	13.0		2.178	1.22	4.11	3.64
17-Apr-95	13.3		2.227	1.33	3.96	3.54
21-Jun-95	13.5		2.260	1.25	4.07	3.61

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE		SUBBASE		BASE		HMAC		TEMPERATURE		AVERAGE ERROR
		MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	SURFACE	AIR	
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
8-Aug-89	BWP	25.3	2.5			142.0	30.3	271.0	76.0	92.9	77.2	2.3

SUMMARY DATA SHEET

LOCATION

SHRP ID 1094-1

STATE		DISTRICT				COUNTY				LATITUDE, LONGITUDE	ELEVATION (FT)	ROUTE NO	FUNCTIONAL CLASS
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN				
Texas	48	San Antonio	15	15	15	Bexar	29	15	15	29.60, 98.71	1109	16	2

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	16.1	32.0	92	15		

INVENTORY

SECTION LENGTH	LANE NOS	LANE WIDTH	INNER PAVED SHOULDER SURFACE TYPE	INNER PAVED SHOULDER WIDTH	OUTER PAVED SHOULDER SURFACE TYPE	OUTER PAVED SHOULDER WIDTH	PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
FT		FT		FT		FT				
500	2	12	AC	6	AC	10	1	None	01-Nov-74	01-Aug-76

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Coarse Grained Soil: Clayey Sand with Gravel				
2	GB	Base: Crushed Stone	8.40		8.00	
3	AC	Seal Coat			0.50	
3/4	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	1.20	1.16	1.00	
4/5	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	0.70	0.63	0.80	
	AC	**Total AC Thickness**	**1.90**	**1.79**	**2.30**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
2280		243,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
14-Aug-89	13.0		0.131	0.00	5.58	5.58
27-Mar-91	14.7		0.153	0.00	3.61	3.61
24-Sep-91	15.2		0.159	0.00	5.81	5.81
5-Apr-93	16.7		0.184	0.00	4.36	4.36
19-Sep-95	19.1		0.226	0.00	0.00	0.00

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
14-Aug-89	13.0		0.131	0.00	0.00	0.021	0.002
27-Mar-91	14.7		0.153	0.00	0.00	0.011	0.001
24-Sep-91	15.2		0.159	0.00	0.00	0.011	0.001

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
20-Mar-90	13.6		0.138	0.88	4.63	3.98
11-Apr-91	14.7		0.153	0.91	4.57	3.95
14-Dec-92	16.4		0.179	0.88	4.62	3.98
21-Jul-94	18.0		0.204	0.96	4.49	3.89

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE MEAN	SUBGRADE STD. DEV.	SUBBASE MEAN	SUBBASE STD. DEV.	BASE MEAN	BASE STD. DEV.	HMAC MEAN	HMAC STD. DEV.	TEMPERATURE SURFACE	TEMPERATURE AIR	AVERAGE ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
7-Feb-90	BWP	29.9	7.5			231.7	150.3	1375.0	0.0	55.6	64.7	7.3

SUMMARY DATA SHEET

LOCATION

SHRP ID 1096-1

STATE		DISTRICT				COUNTY				LATITUDE , LONGITUDE	ELEVATION (FT)	ROUTE NO	FUNCTIONAL CLASS
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN				
Texas	48	San Antonio	15	15	15	Medina	325	163	163	29.36, 98.34	774	90	2

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	12.0	25.8	113	10		

INVENTORY

SECTION LENGTH	LANE NOS	LANE WIDTH	INNER PAVED SHOULDER SURFACE TYPE	INNER PAVED SHOULDER WIDTH	OUTER PAVED SHOULDER SURFACE TYPE	OUTER PAVED SHOULDER WIDTH	PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
FT		FT		FT		FT				
500	2	12	AC	6	AC	12	1	None	01-Jul-79	01-Apr-81

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine Grained Soil: Fat Clay with Sand				
2	TS	Subbase: Lime-Treated Soils			6.0	3.0
2/3	GB	Base: Crushed Stone	8.10		8.00	
4	AC	Seal Coat			0.50	
3	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	5.00	4.92		
4/5	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	1.50	1.48	6.00	
5/6	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	0.60	0.59	0.80	
	AC	**Total AC Thickness**	**7.10**	**6.98**	**7.30**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
5900		1,126,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
26-Mar-91	10.0		0.735	0.00	7.19	7.19
2-Apr-93	12.0		0.814	0.00	7.97	7.97
23-Mar-95	14.0		0.891	0.00	66.50	66.50

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
26-Mar-90	9.0		0.696	2.12	3.10	2.88
6-Dec-91	10.7		0.762	2.31	2.92	2.75
22-Dec-92	11.7		0.803	2.31	2.92	2.74
4-Oct-94	13.5		0.872	2.33	2.90	2.73

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
26-Mar-91	10.0		0.735	0.00	0.00	0.077	0.007

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE MEAN	SUBGRADE STD. DEV.	SUBBASE MEAN	SUBBASE STD. DEV.	BASE MEAN	BASE STD. DEV.	HMAC MEAN	HMAC STD. DEV.	TEMPERATURE SURFACE	TEMPERATURE AIR	AVERAGE ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
12-Feb-90	BWP	16.4	2.4			127.9	51.3	1102.0	45.0	68.7	72.0	1.7

SUMMARY DATA SHEET

LOCATION

SHRP ID 1113-1

STATE		DISTRICT				COUNTY				LATITUDE ,	ELEVATION	ROUTE	FUNCTIONAL
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN	LONGITUDE	(FT)	NO	CLASS
Texas	48	Tyler	10	10	10	Rusk	401	201	201	31.96, 94.70	445	259	2

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	38.4	50.3	72	5		

INVENTORY

SECTION	LANE		INNER PAVED SHOULDER		OUTER PAVED SHOULDER		PAVEMENT	SUB-SURFACE	CONSTRUCTION	TRAFFIC OPEN
LENGTH	NOS	WIDTH	SURFACE TYPE	WIDTH	SURFACE TYPE	WIDTH	TYPE	DRAINAGE	DATE	DATE
FT		FT		FT		FT				
500	2	12	AC	4	AC	10	1	None	01-Jan-86	01-Jan-86

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine Grained Soil: Sandy Lean Clay				
2	GB	Base: Soil-Aggregate Mixture (predominently coarse grained)	11.50		12.00	
3	AC	Seal Coat: Chip Seal	0.70	0.63	0.50	
4	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	0.80	0.76	1.00	
	AC	**Total AC Thickness**	**1.50**	**1.38**	**1.50**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
4700		1,738,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
3-Jun-92	6.425		0.678	7.10	7.10	7.10

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
25-Jun-91	5.482		0.634	0.00	0.00	0.177	0.005

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
20-Apr-90	4.3		0.568	0.76	4.70	4.11
18-Dec-91	6.0		0.661	0.92	4.56	3.94

BACK-CALCULATED MODULI

FWD TEST	TEST	SUBGRADE		SUBBASE		BASE		HMAC		TEMPERATURE		AVERAGE
DATE	LINE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	SURFACE	AIR	ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
2-Apr-90	BWP	22.6	2.4			57.0	4.5	700.0	0.0	68.0	71.1	13.8

SUMMARY DATA SHEET

LOCATION

SHRP ID 1130-1

STATE		DISTRICT				COUNTY				LATITUDE ,	ELEVATION	ROUTE	FUNCTIONAL
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN	LONGITUDE	(FT)	NO	CLASS
Texas	48	San Antoonio	15	15	15	Guadalupe	187	95	95	29.56, 97.94	519	123	6

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	14.4	35.3	103	19		

INVENTORY

SECTION LENGTH	LANE NOS	LANE WIDTH	INNER PAVED SHOULDER SURFACE TYPE	INNER PAVED SHOULDER WIDTH	OUTER PAVED SHOULDER SURFACE TYPE	OUTER PAVED SHOULDER WIDTH	PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
FT		FT		FT		FT				
500	2	12	AC	2	AC	20	1	None	01-Oct-71	01-Aug-72

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine Grained Soil: Fat Caly with Sand				
2	TS	Subbase: Lime-Treated Soil	8.00		6.00	3 (30)
3	GB	Base: Crushed Stone	17.90		18.00	
4	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	2.30	2.23	1.50	
5	AC	Seal Coat: Chip Seal	0.40	0.33	0.80	
	AC	**Total AC Thickness**	**2.70**	**2.55**	**2.30**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
1620		842,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
25-Mar-91	18.7		0.820	53.39	54.90	54.90
19-Mar-92	19.6		0.836	85.57	89.08	92.10

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
4-Apr-90	17.7		0.803	3.70	1.85	1.91
18-Mar-92	19.6		0.836	3.75	1.83	1.89

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
25-Mar-91	18.7		0.820	32.50	5.00	0.438	0.130
19-Mar-92	19.6		0.836	40.00	10.00	0.589	0.097

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE MEAN	SUBGRADE STD. DEV.	SUBBASE MEAN	SUBBASE STD. DEV.	BASE MEAN	BASE STD. DEV.	HMAC MEAN	HMAC STD. DEV.	TEMPERATURE SURFACE	TEMPERATURE AIR	AVERAGE ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
5-Feb-90	BWP	22.9	2.0			34.9	5.2	1612.0	56.0	36.0	48.7	4.6

SUMMARY DATA SHEET

LOCATION

SHRP ID 1168-1

STATE		DISTRICT				COUNTY				LATITUDE ,	ELEVATION	ROUTE	FUNCTIONAL
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN	LONGITUDE	(FT)	NO	CLASS
Texas	48	Tyler	10	10	10	Wood	499	250	250	32.68, 95.47	418	564	8

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	72.8	47.8	69	6		

INVENTORY

SECTION	LANE		INNER PAVED SHOULDER		OUTER PAVED SHOULDER		PAVEMENT	SUB-SURFACE	CONSTRUCTION	TRAFFIC OPEN
LENGTH	NOS	WIDTH	SURFACE TYPE	WIDTH	SURFACE TYPE	WIDTH	TYPE	DRAINAGE	DATE	DATE
FT		FT		FT		FT				
500	1	12			AC	8	1	None	01-Sep-85	01-Sep-85

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Coarse-Grained Soil: Silty Sand				
2	GB	Base: Soil-Aggregate Mixture (predominently coarse grained)	10.40		11.00	
3	AC	Seal Coat: Chip Seal	0.40	0.36	0.50	
4	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	0.80	0.80	1.00	
	AC	**Total AC Thickness**	**1.20**	**1.16**	**1.50**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
140	1200	37,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
24-Jun-91	5.81		0.010	3.44	5.05	5.05
12-Aug-93	7.95		0.013	30.35	34.55	34.55
20-Jul-95	9.89		0.017	39.72	46.18	46.18

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
24-Jun-91	5.814		0.01	5.00	0.00	0.084	0.017

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
25-Apr-90	4.6		0.008	1.02	4.39	3.83
22-Mar-91	5.6		0.009	1.12	4.24	3.74
26-May-93	7.7		0.013	1.18	4.16	3.68
21-Feb-95	9.5		0.016	1.47	3.79	3.41

BACK-CALCULATED MODULI

FWD TEST	TEST	SUBGRADE		SUBBASE		BASE		HMAC		TEMPERATURE		AVERAGE
DATE	LINE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	SURFACE	AIR	ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
24-Aug-89	BWP	18.7	5.7			33.4	9.7	225.0	0.0	106.7	95.0	6.6

SUMMARY DATA SHEET

LOCATION

SHRP ID 1178-1

STATE		DISTRICT				COUNTY				LATITUDE , LONGITUDE	ELEVATION (FT)	ROUTE NO	FUNCTIONAL CLASS
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN				
Texas	48	Bryan	17	17	17	Burleson	51	26	26	30.56, 96.67	425	21	2

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	54.0	33.4	99	2		

INVENTORY

SECTION LENGTH	LANE		INNER PAVED SHOULDER		OUTER PAVED SHOULDER		PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
	NOS	WIDTH	SURFACE TYPE	WIDTH	SURFACE TYPE	WIDTH				
FT		FT		FT		FT				
500	2	12	AC	4	AC	10	1	None	01-Jul-88	01-Jul-88

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine Grained Soil: Lean Clay with Sand				
2	TS	Subbase: Lime-Treated Soil	4.50		6.00	4.0
3	GB	Base: Soil-Aggregate Mixture (predominently coarse grained)	10.80		10.00	
4	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	6.40	6.41	6.00	
5	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	2.10	2.10	2.00	
	AC	**Total AC Thickness**	**8.50**	**8.51**	**8.00**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
6000		933,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
28-May-91	2.9		0.192	0.00	4.79	4.79
13-Jul-93	5.0		0.289	0.00	9.45	9.45
17-Mar-95	6.7		0.361	0.86	6.54	6.54
11-May-95	6.9		0.367	0.00	0.00	0.00

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
28-May-91	2.9		0.192	0.00	0.00	0.054	0.004
13-Jul-93	5.0		0.504	0.00	0.00	0.127	0.002

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
18-Apr-90	1.8		0.144	1.77	3.45	3.16
18-Mar-92	3.7		0.230	2.46	2.79	2.64
2-Jun-93	4.9		0.499	3.13	2.26	2.22

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE		SUBBASE		BASE		HMAC		TEMPERATURE		AVERAGE ERROR
		MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	SURFACE	AIR	
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
9-Jun-89	BWP	23.5	2.5			224.0	118.1	639.0	71.0	84.3	75.5	1.5

SUMMARY DATA SHEET

LOCATION

SHRP ID 3579-1

STATE		DISTRICT				COUNTY				LATITUDE ,	ELEVATION	ROUTE	FUNCTIONAL
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN	LONGITUDE	(FT)	NO	CLASS
Texas	48	Tyler	10	10	10	Van Zandt	467	234	234	32.62, 95.85	49	19	6

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	79.8	43.4	72	4		

INVENTORY

SECTION LENGTH	LANE NOS	LANE WIDTH	INNER PAVED SHOULDER SURFACE TYPE	INNER PAVED SHOULDER WIDTH	OUTER PAVED SHOULDER SURFACE TYPE	OUTER PAVED SHOULDER WIDTH	PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
FT		FT		FT		FT				
500	1	12			AC	10	1	None	01-Nov-87	01-Nov-87

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine Grained Soil: Sandy Lean Clay				
2	TS	Subbase: Lime-Treated Soil	9.20		6.00	3.0
3	GB	Base: Soil-Aggregate Mixture (predominently coarse grained)	10.80		10.00	
4	AC	Seal Coat: Chip Seal	0.60	0.59	0.50	
5	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	1.10	1.06	1.50	
	AC	**Total AC Thickness**	**1.70**	**1.65**	**2.00**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
2700		1,792,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
24-Jun-91	3.647		0.353	0.00	0.00	0.00
21-Dec-92	5.142		0.402	0.00	0.00	0.00
12-Aug-93	5.784		0.443	0.00	0.00	0.00
7-Sep-94	6.855		0.534	0.00	0.00	0.00
20-Jul-95	7.721		0.639	0.22	1.27	1.27

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
24-Jun-91	3.647		0.353	0.00	0.00	0.041	0.004
21-Dec-92	5.14		0.402	0.00	0.00	0.111	0.007
20-Jul-95	7.715		0.639	0.00	0.00	0.197	0.005

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
23-Aug-90	2.8		0.327	1.29	4.01	3.57
21-Mar-91	3.4		0.345	1.38	3.90	3.49
17-Feb-93	5.3		0.411	1.41	3.86	3.47
28-Oct-94	7.0		0.547	1.38	3.90	3.50

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE MEAN	SUBGRADE STD. DEV.	SUBBASE MEAN	SUBBASE STD. DEV.	BASE MEAN	BASE STD. DEV.	HMAC MEAN	HMAC STD. DEV.	TEMPERATURE SURFACE	TEMPERATURE AIR	AVERAGE ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
28-Aug-89	BWP	26.5	3.4	481.3	249.4	96.5	17.5	150.0	0.0	120.7	92.6	1.4

SUMMARY DATA SHEET

LOCATION

SHRP ID 3729-1

STATE		DISTRICT				COUNTY				LATITUDE, LONGITUDE	ELEVATION (FT)	ROUTE NO	FUNCTIONAL CLASS
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN				
Texas	48	Pharr	21	21	21	Cameron	61	31	31	26.09, 97.58	38	83	2

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	3.9	26.5	113	8		

INVENTORY

SECTION	LANE		INNER PAVED SHOULDER		OUTER PAVED SHOULDER		PAVEMENT	SUB-SURFACE	CONSTRUCTION	TRAFFIC OPEN
LENGTH	NOS	WIDTH	SURFACE TYPE	WIDTH	SURFACE TYPE	WIDTH	TYPE	DRAINAGE	DATE	DATE
FT		FT		FT		FT				
500	2	12	AC	3	AC	10	1	None	01-Jun-83	01-Jun-83

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine Grained Soil: Lean Inorganic Clay				
2	TS	Subbase: Lime-Treated Soil			12.00	3.0
3	GB	Base: Soil-Aggregate Mixture (predominently coarse grained)	10.50		10.00	
4	AC	Binder: Hot Mixed, Hot Laid AC, Dense Graded	8.10	8.12	8.00	
5	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	1.90	1.80	2.00	
	AC	**Total AC Thickness**	**10.00**	**9.92**	**10.00**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
20000		2,626,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
9-Apr-91	7.86		1.626	0.00	15.91	15.91
18-Mar-92	8.803		1.707	0.00	25.49	25.49
30-Mar-93	9.836		1.792	4.63	26.54	26.54
21-Mar-95	11.81		1.954	12.16	34.90	34.90

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
30-Mar-90	6.8		1.532	1.52	3.72	3.36
19-Apr-91	7.9		1.629	1.55	3.69	3.34
19-Mar-92	8.8		1.708	1.63	3.60	3.27
5-Aug-93	10.2		1.821	1.67	3.56	3.24
7-Mar-95	11.8		1.951	2.08	3.14	2.92

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
9-Apr-91	7.86		1.626	22.50	0.00	0.381	0.019
18-Mar-92	8.8		1.707	30.00	0.00	0.451	0.023

BACK-CALCULATED MODULI

FWD TEST	TEST	SUBGRADE		SUBBASE		BASE		HMAC		TEMPERATURE		AVERAGE
DATE	LINE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	SURFACE	AIR	ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
23-Feb-90	BWP	15.0	2.7	59.9	70.6	155.5	108.8	1592.0	183.0	50.7	58.8	1.1

SUMMARY DATA SHEET

LOCATION

SHRP ID 3739-1

STATE		DISTRICT				COUNTY				LATITUDE , LONGITUDE	ELEVATION (FT)	ROUTE NO	FUNCTIONAL CLASS
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN				
Texas	48	Pharr	21	21	21	Kenedy	261	66	66	26.98, 97.80	36	77	2

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	5.8	23.9	117	9		

INVENTORY

SECTION LENGTH	LANE		INNER PAVED SHOULDER		OUTER PAVED SHOULDER		PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
	NOS	WIDTH	SURFACE TYPE	WIDTH	SURFACE TYPE	WIDTH				
FT		FT		FT		FT				
500	2	12	AC	4	AC	10	1	None	01-May-82	01-May-82

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Coarse Grained Soil: Poorly Graded Sand				
2	TS	Subbase: Lime-Treated Soil	7.40		8.00	3.0
3	GB	Base: Soil-Aggregate Mixture (predominently coarse grained)	11.40		10.00	0.5
4	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	1.50	1.42	2.50	
5	AC	Seal Coat: Chip Seal	0.30	0.30	0.30	
	AC	**Total AC Thickness**	**1.80**	**1.72**	**2.80**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
4800		2,777,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
9-Apr-91	8.9		1.343	0.00	0.98	0.98
30-Aug-91	9.3		1.375	0.75	2.66	2.66
18-Mar-92	9.9		1.421	4.52	12.82	12.82
30-Mar-93	10.9		1.512	5.27	9.31	9.31

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
9-Apr-91	8.945		1.343	0.00	0.00	0.165	0.016
30-Aug-91	9.334		1.375	0.00	0.00	0.247	0.010
18-Mar-92	9.882		1.421	0.00	0.00	0.186	0.004

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
29-Mar-90	7.9		1.262	2.00	3.21	2.97
18-Apr-91	9.0		1.345	2.17	3.05	2.84
20-Mar-92	9.9		1.422	2.23	2.99	2.80
6-Aug-93	11.3		1.545	2.53	2.72	2.59
14-Dec-93	11.6		1.577	2.53	2.73	2.59
22-Apr-94	12.0		1.710	2.57	2.70	2.57
14-Jul-94	12.2		1.732	2.36	2.88	2.71

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE		SUBBASE		BASE		HMAC		TEMPERATURE		AVERAGE ERROR
		MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	SURFACE	AIR	
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
26-Feb-90	BWP	15.1	2.0			81.7	38.4	650.0	0.0	75.4	75.0	4.8

SUMMARY DATA SHEET

LOCATION

SHRP ID 3875-1

STATE		DISTRICT				COUNTY				LATITUDE,	ELEVATION	ROUTE	FUNCTIONAL
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN	LONGITUDE	(FT)	NO	CLASS
Texas	48	Amarillo	4	4	4	Sherman	421	211	211	36.17,102.03	3602	287	2

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Dry Freeze	367.5	19.2	51	6		

INVENTORY

SECTION	LANE		INNER PAVED SHOULDER		OUTER PAVED SHOULDER		PAVEMENT	SUB-SURFACE	CONSTRUCTION	TRAFFIC OPEN
LENGTH	NOS	WIDTH	SURFACE TYPE	WIDTH	SURFACE TYPE	WIDTH	TYPE	DRAINAGE	DATE	DATE
FT		FT		FT		FT				
500	2	12	PCC	4	PCC	4	1	None	01-Jun-84	01-Nov-85

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine-Grained Soil: Lean Clay with Sand				
2	GB	Base: Soil-Aggregate Mixture (predominently coarse grained)	16.70		18.00	
3	AC	Seal Coat: Fog Seal	0.60	0.54	0.50	
4	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	1.00	0.94	1.50	
	AC	**Total AC Thickness**	**1.60**	**1.47**	**2.00**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
3800		1,872,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
12-Jun-91	5.614		0.879	0.00	0.00	0.00

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
22-Feb-91	5.3		0.858	1.05	4.35	3.81

BACK-CALCULATED MODULI

FWD TEST	TEST	SUBGRADE		SUBBASE		BASE		HMAC		TEMPERATURE		AVERAGE
DATE	LINE	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	MEAN	STD. DEV.	SURFACE	AIR	ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
7-Nov-91	BWP	38.5	5.1			102.5	11.9	3850.0	0.0	24.7	28.9	4.5

SUMMARY DATA SHEET

LOCATION

SHRP ID 9005-1

STATE		DISTRICT				COUNTY				LATITUDE , LONGITUDE	ELEVATION (FT)	ROUTE NO	FUNCTIONAL CLASS
NAME	CODE	NAME	SHRP	PMIS	UZAN	NAME	SHRP	PMIS	UZAN				
Texas	48	San Antonio	15	15	15	Bexar	29	15	15	29.52, 98.72	910	1560	8

ENVIRONMENT, SWELLING AND FROST

CLIMATE REGION	FREEZING INDEX	PRECIPITATION	DAYS ABOVE	YEARS OF CLIMATE DATA	T.M.I.	EXCHANGE SODIUM RATE
	F-DAYS	INCH	90 oF	YEARS		%
Wet No Freeze	12.8	29.6	105	5		

INVENTORY

SECTION LENGTH	LANE NOS	LANE WIDTH	INNER PAVED SHOULDER SURFACE TYPE	INNER PAVED SHOULDER WIDTH	OUTER PAVED SHOULDER SURFACE TYPE	OUTER PAVED SHOULDER WIDTH	PAVEMENT TYPE	SUB-SURFACE DRAINAGE	CONSTRUCTION DATE	TRAFFIC OPEN DATE
FT		FT		FT		FT				
500	1	12			AC	6	1	None	01-Jul-86	01-Sep-86

PAVEMENT LAYERS

LAYER	TYPE	LAYER DESCRIPTION	PRESENTATION	CORE-TEST	INVENTORY	LIME
NO.			INCH	INCH	INCH	%
1	SS	Subgrade: Fine-Grained Soil: Gravelly Fat Clay with Sand				
2	GB	Base: Soil-Aggregate Mixture (predominently fine grained)	9.40		9.00	
3	AC	Seal Coat: Chip Seal	0.40	0.41	0.50	
4	AC	Original Surface: Hot Mixed, Hot Laid, Dense Graded	1.10	1.07	1.00	
	AC	**Total AC Thickness**	**1.50**	**1.48**	**1.50**	

TRAFFIC

ADT IN THE FIRST YEAR	ADT AFTER 20 YEARS	20 YEARS CUMULATIVE ESAL
1250		373,000

PAVEMENT CONDITION

FATIGUE CRACKING

SURVEY DATE	AGE	AADT	18 KIP ESAL	A ONLY	A+L	A+L+P
	YEARS	VPD	MILLION	% W. P.	% W. P.	% W. P.
10-Oct-90	4.1		0.122	12.59	29.49	29.49
27-Mar-91	4.6		0.126	1.94	23.43	23.43
26-Aug-91	5.0		0.130	7.53	29.84	29.84
5-Apr-93	6.6		0.150	5.81	5.81	5.81
16-Feb-96	9.5		0.185	16.47	43.83	43.83
9-Jul-96	9.9		0.190	25.30	50.59	50.59

RIDE QUALITY

SURVEY DATE	AGE	AADT	18 KIP ESAL	IRI	PSI	PSR
	YEARS	VPD	MILLION	M/KM	0-5	0-5
6-Apr-90	3.6		0.117	1.21	4.12	3.65
12-Apr-91	4.6		0.127	1.41	3.86	3.46
15-Dec-92	6.3		0.146	1.48	3.78	3.41
3-Oct-94	8.1		0.167	1.80	3.42	3.13

RUTTING

SURVEY DATE	AGE	AADT	18 KIP ESAL	S. RUT	D. RUT	DEPTH	Var(RUT)
	YEARS	VPD	MILLION	% W. P.	% W. P.	INCH	INCH SQ
10-Oct-90	4.11		0.122	0.00	0.00	0.039	0.005
27-Mar-91	4.567		0.126	0.00	0.00	0.025	0.003
16-Feb-96	9.46		0.185	0.00	0.00	0.104	0.014

BACK-CALCULATED MODULI

FWD TEST DATE	TEST LINE	SUBGRADE MEAN	SUBGRADE STD. DEV.	SUBBASE MEAN	SUBBASE STD. DEV.	BASE MEAN	BASE STD. DEV.	HMAC MEAN	HMAC STD. DEV.	TEMPERATURE SURFACE	TEMPERATURE AIR	AVERAGE ERROR
		KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI	oF	oF	%
6-Feb-90	BWP	28.4	11.8			138.6	41.7	1300.0	0.0	58.2	63.1	4.2

APPENDIX B

YEARWISE VARIATION OF TRAFFIC

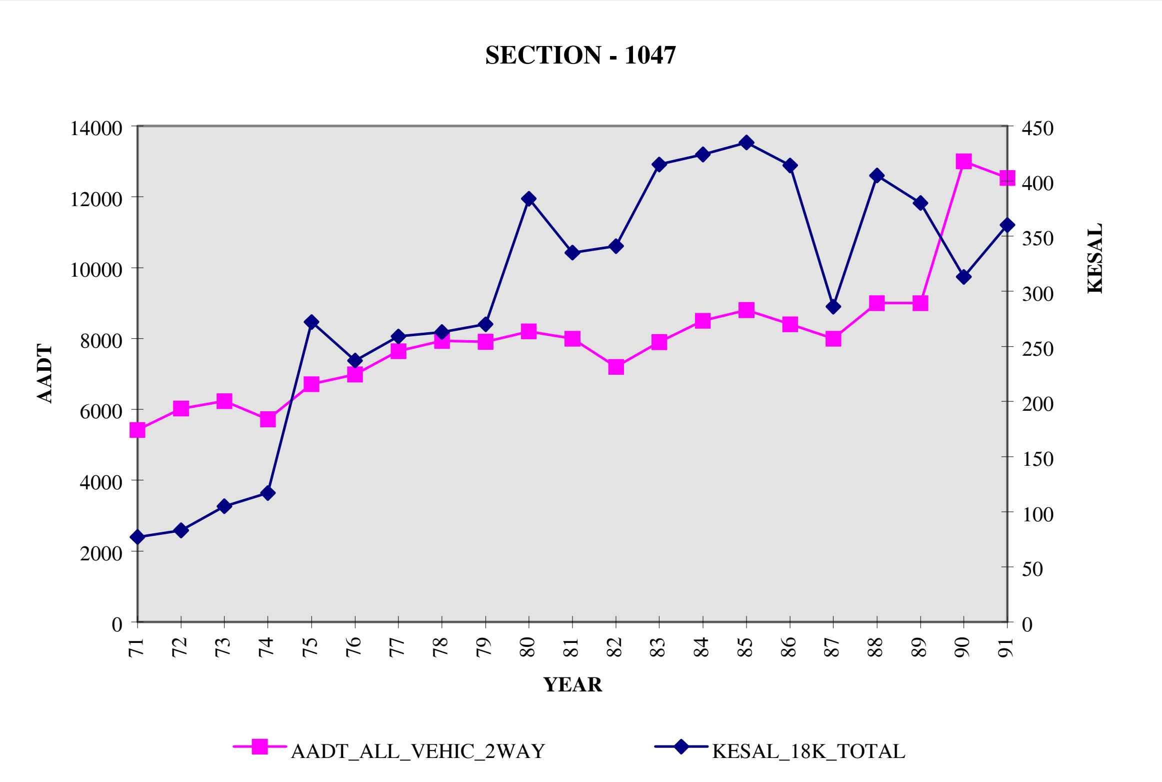


FIGURE B.1 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1047

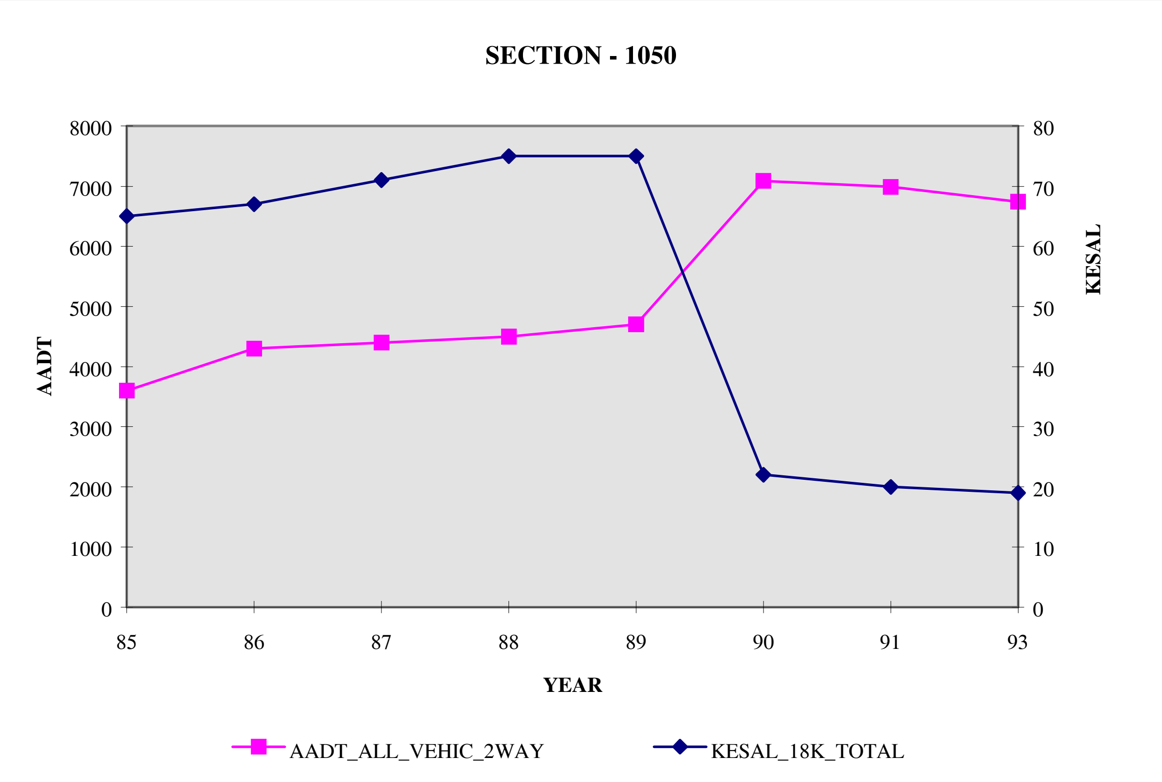


FIGURE B.2 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1050

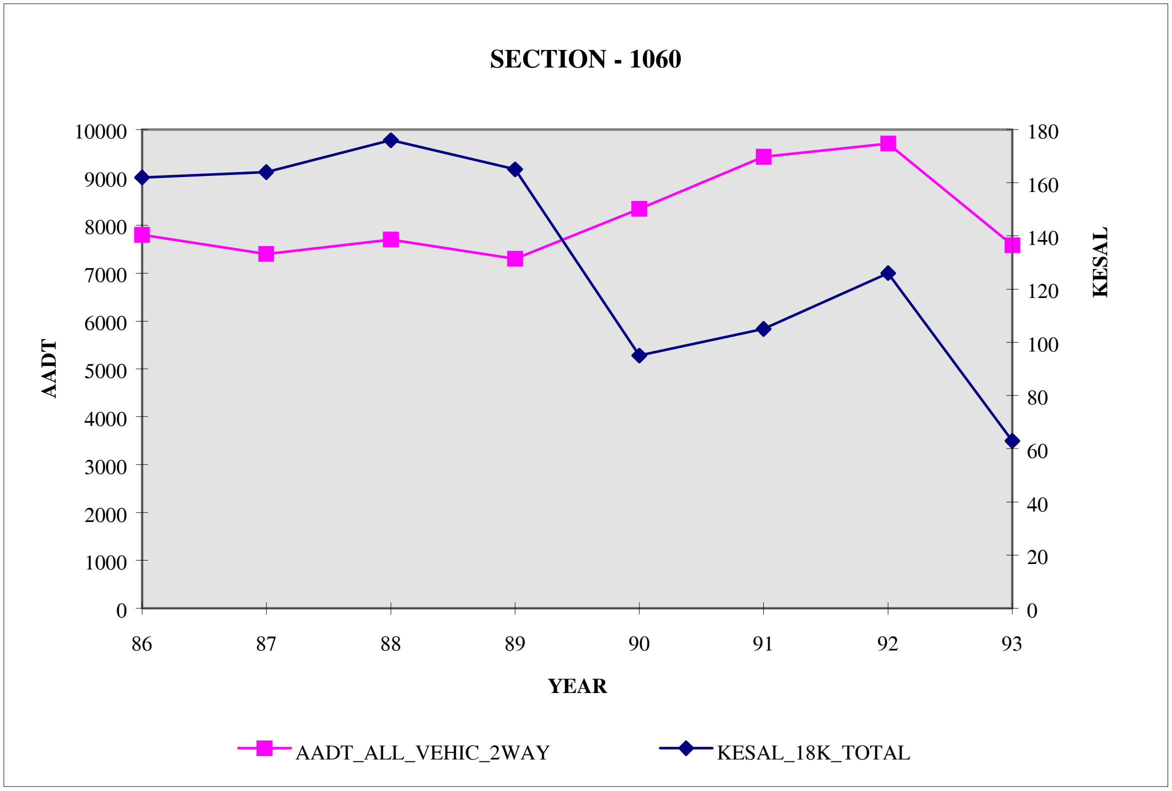


FIGURE B.3 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1060

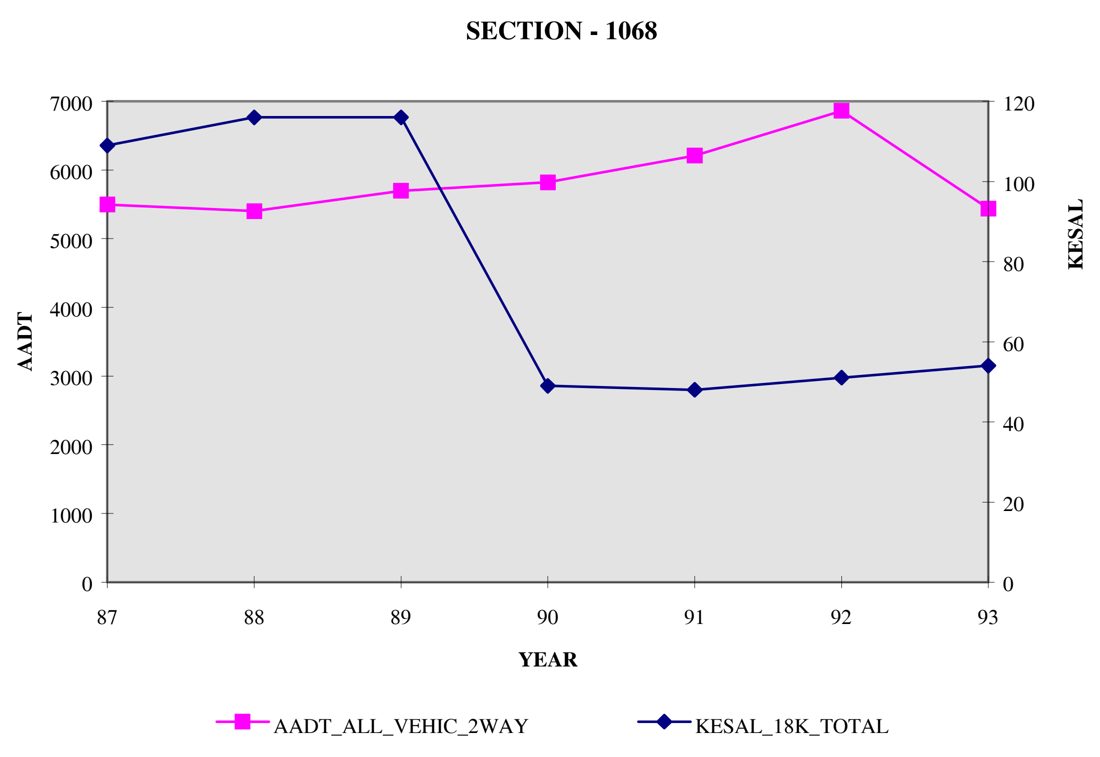


FIGURE B.4 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1068

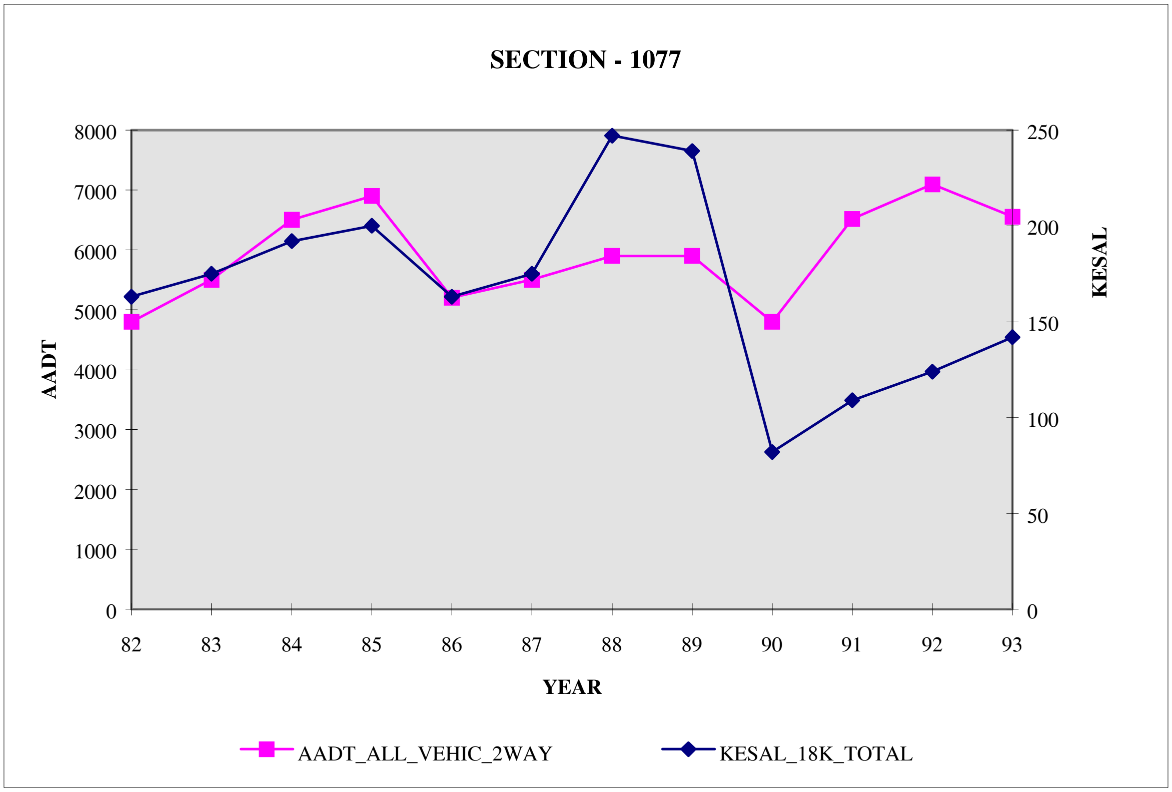


FIGURE B.5 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1077

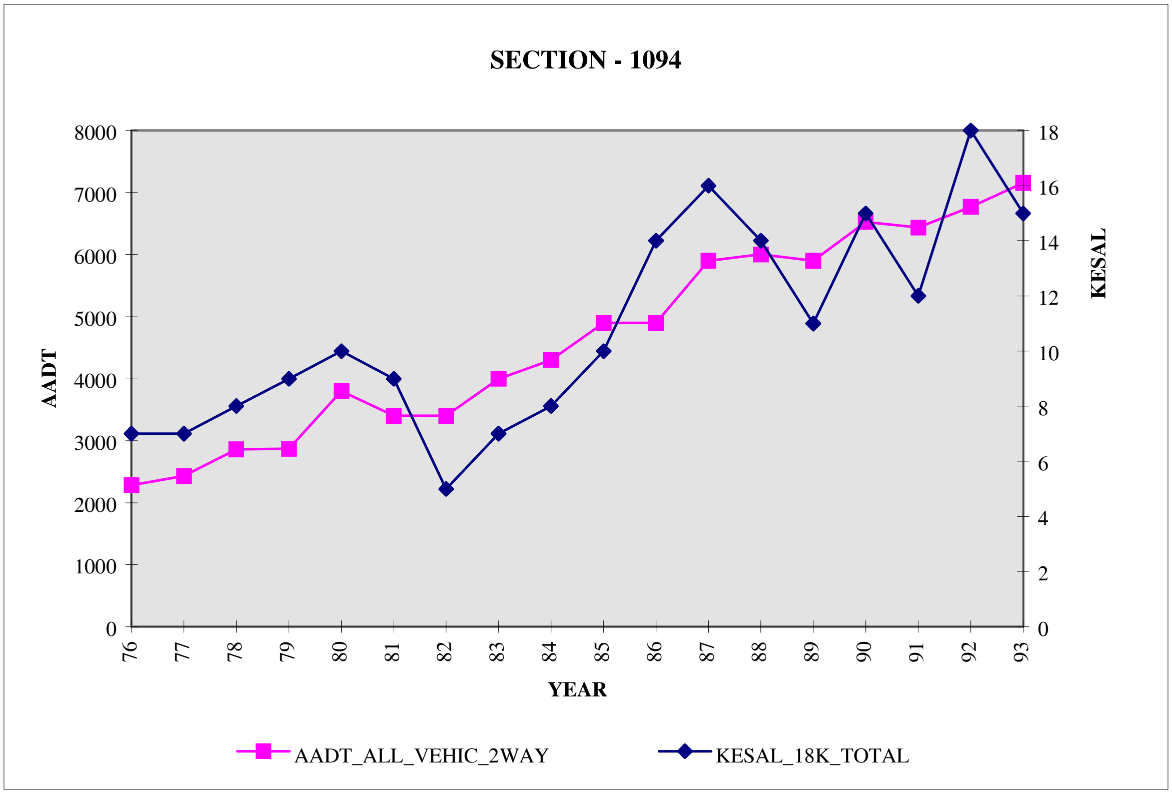


FIGURE B.6 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1094

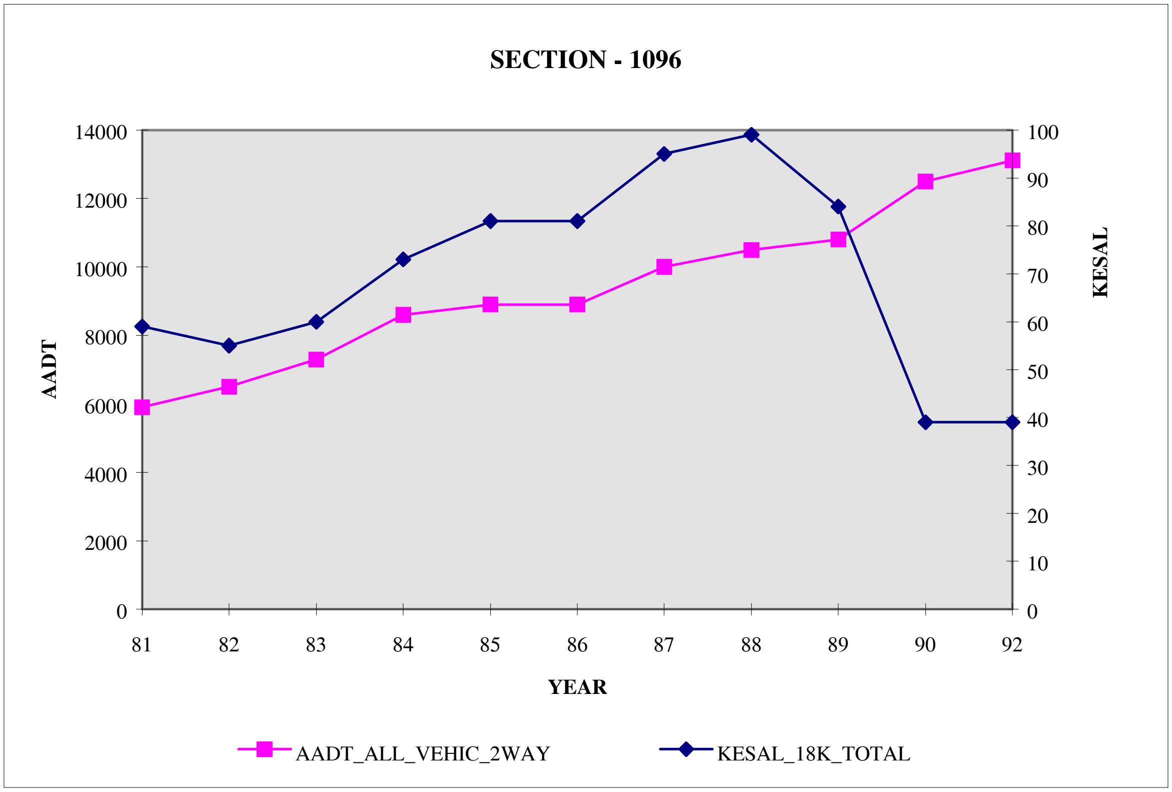


FIGURE B.7 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1096

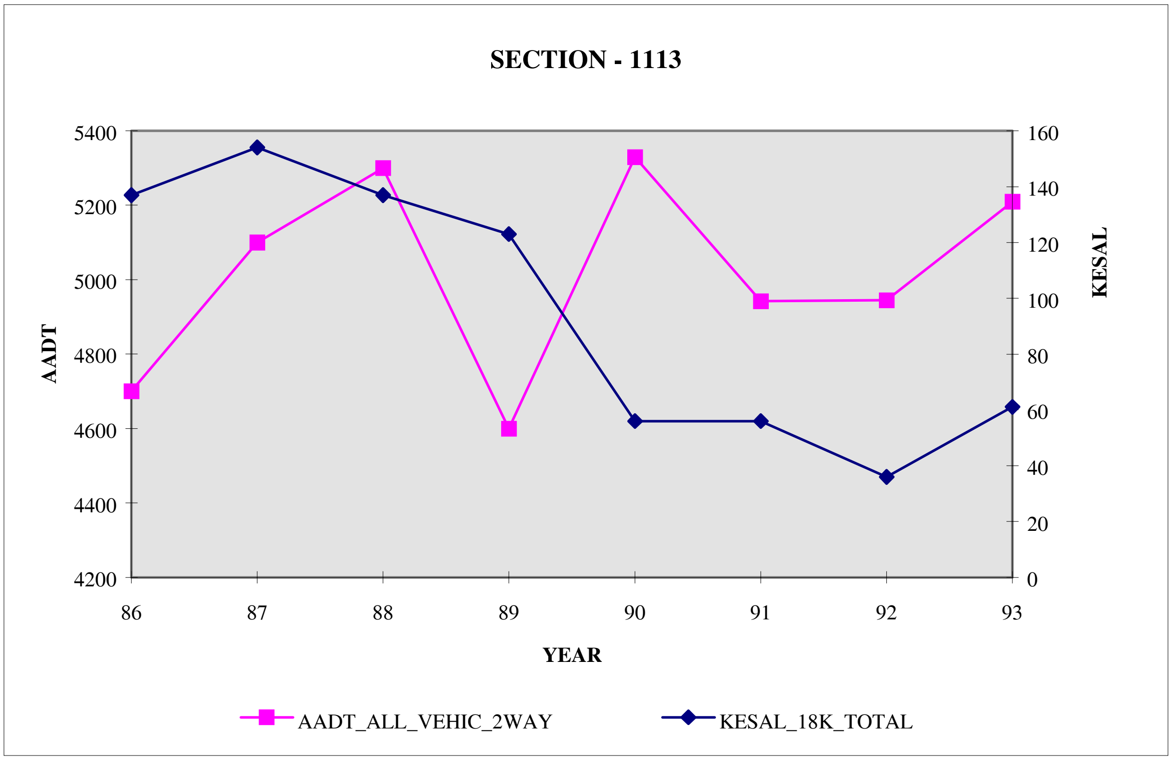


FIGURE B.8 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1113

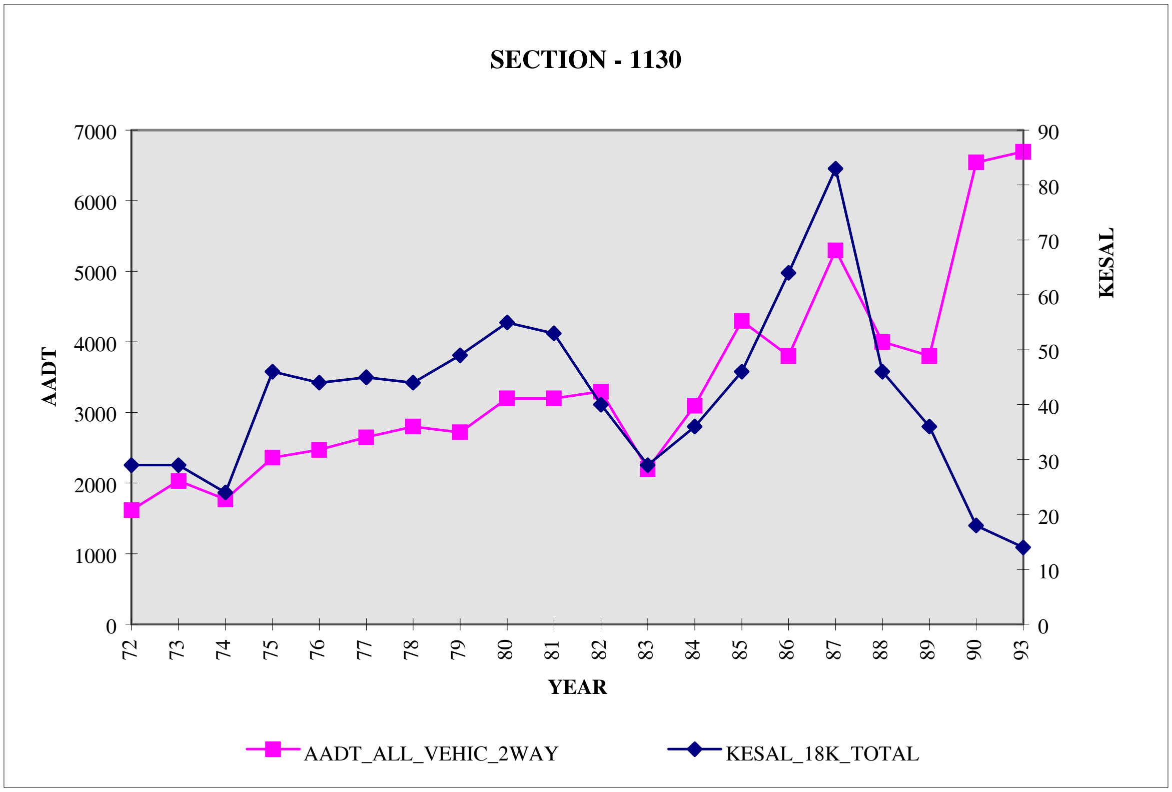


FIGURE B.9 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1130

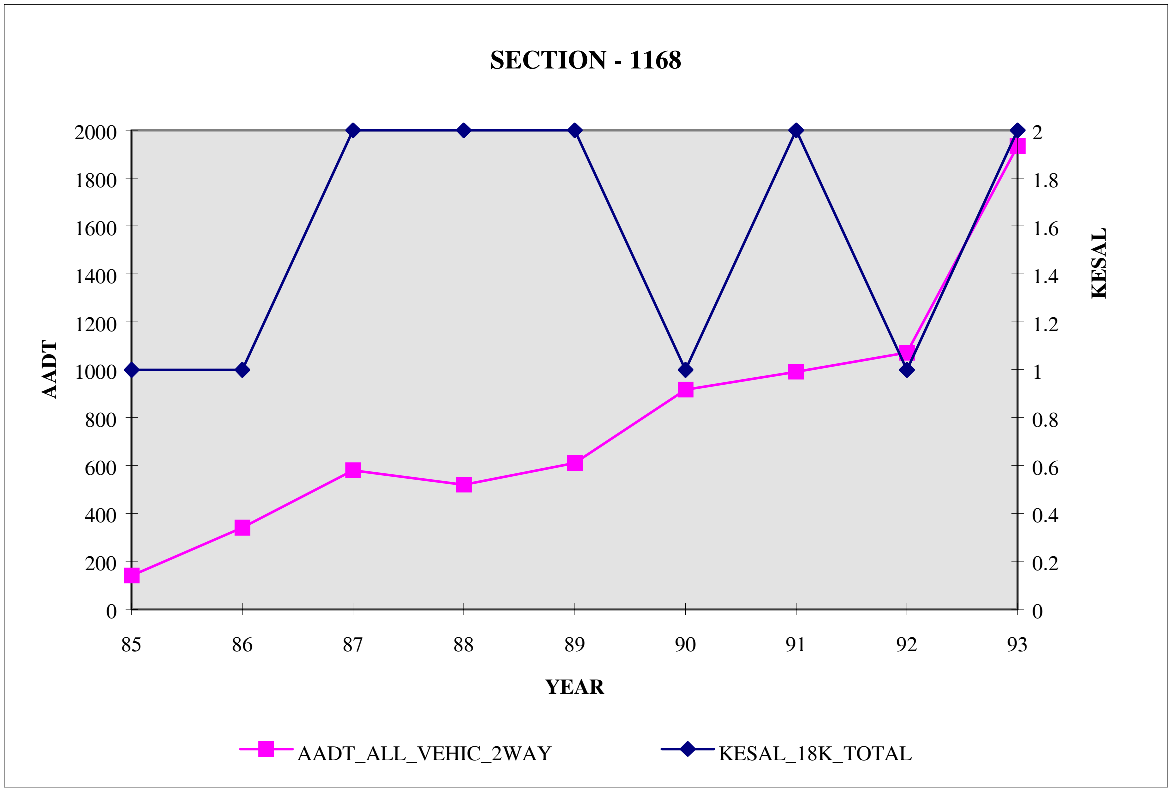


FIGURE B.10 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1168

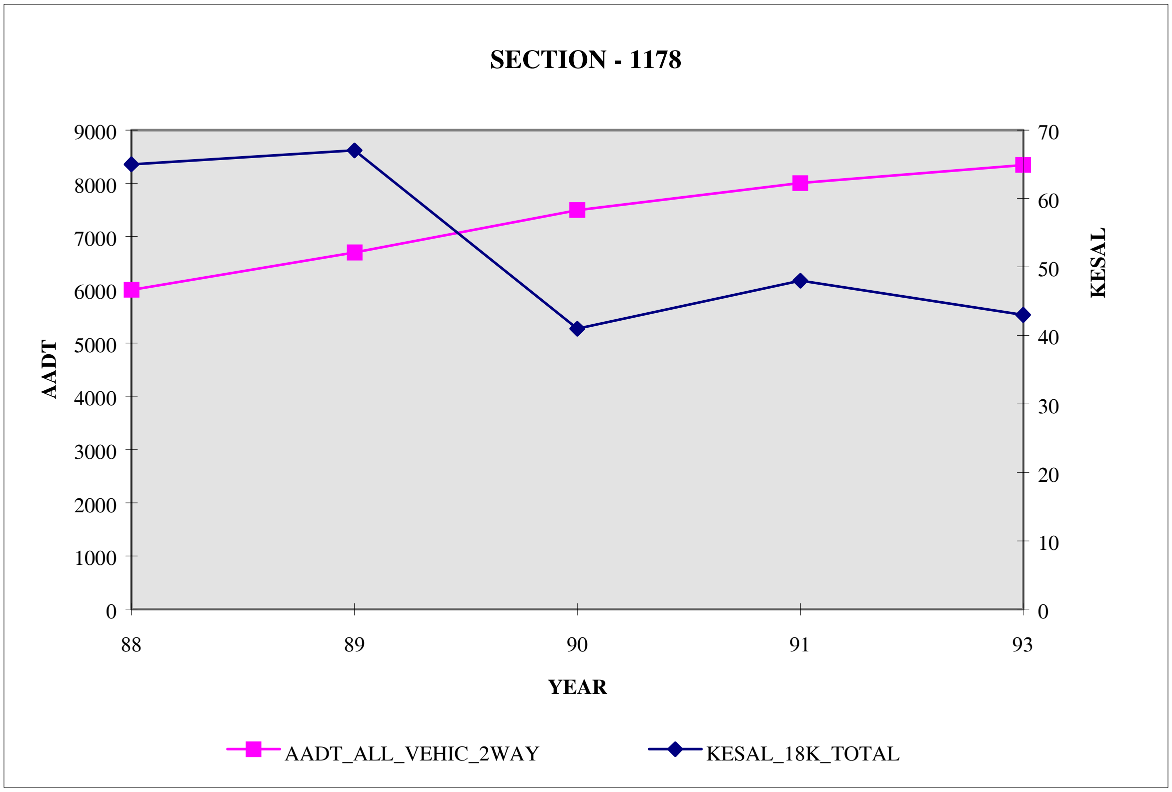


FIGURE B.11 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 1178

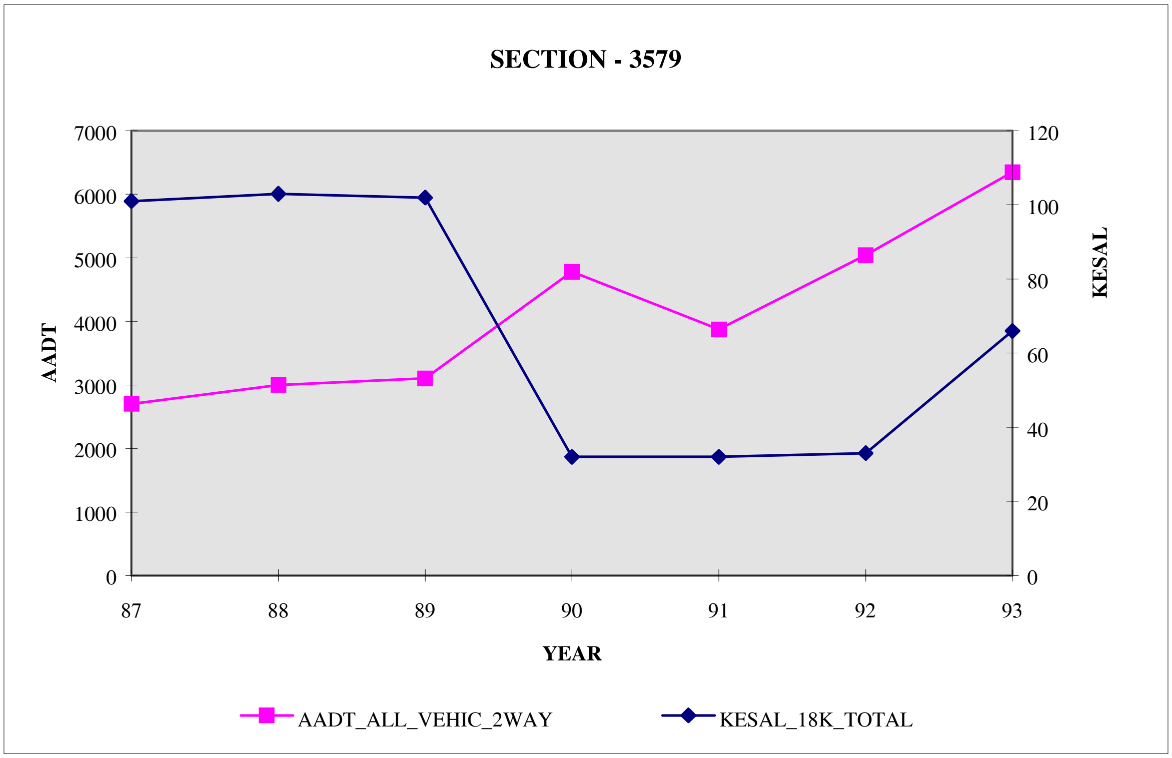


FIGURE B.12 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 3579

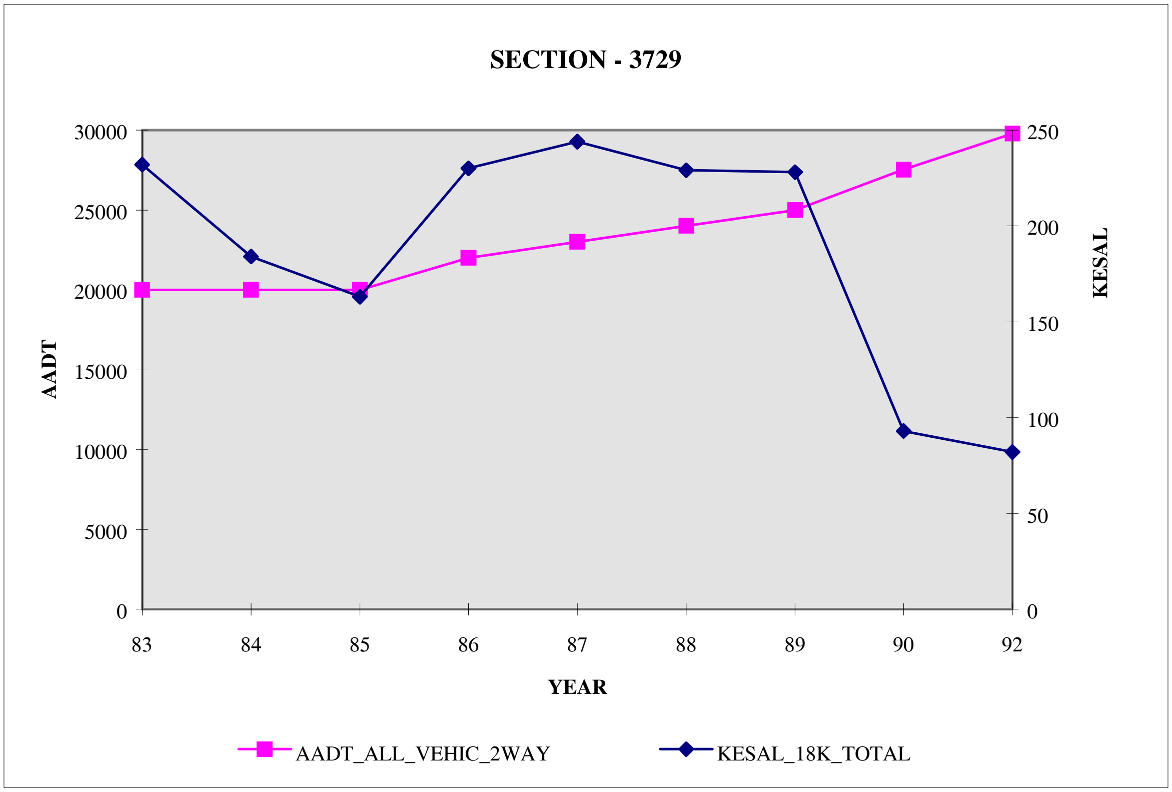


FIGURE B.13 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 3729

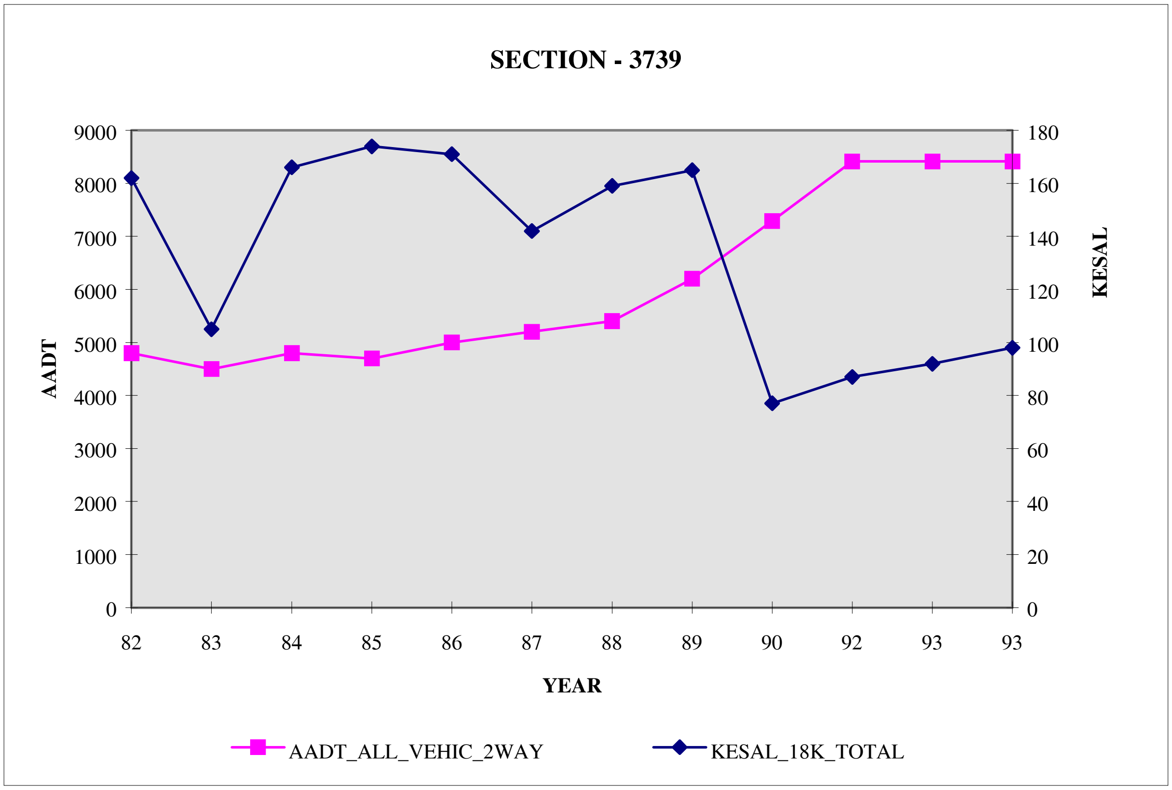


FIGURE B.14 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 3739

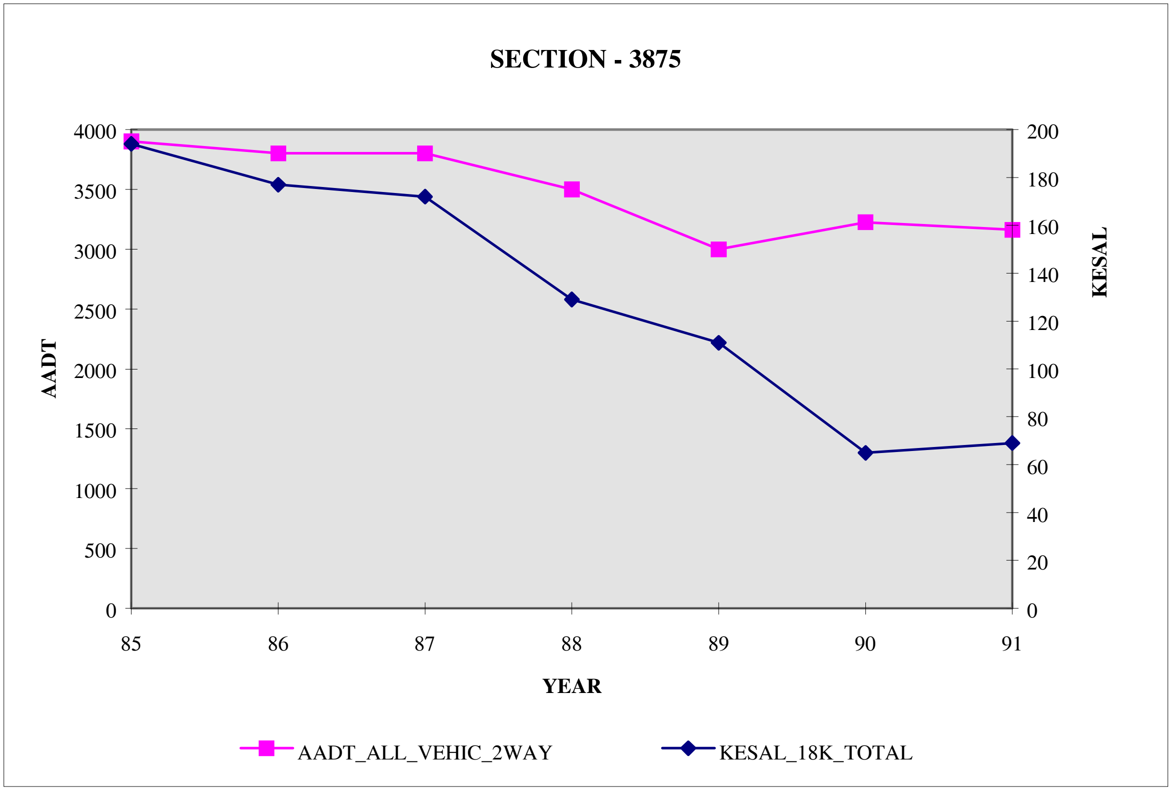


FIGURE B.15 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 3875

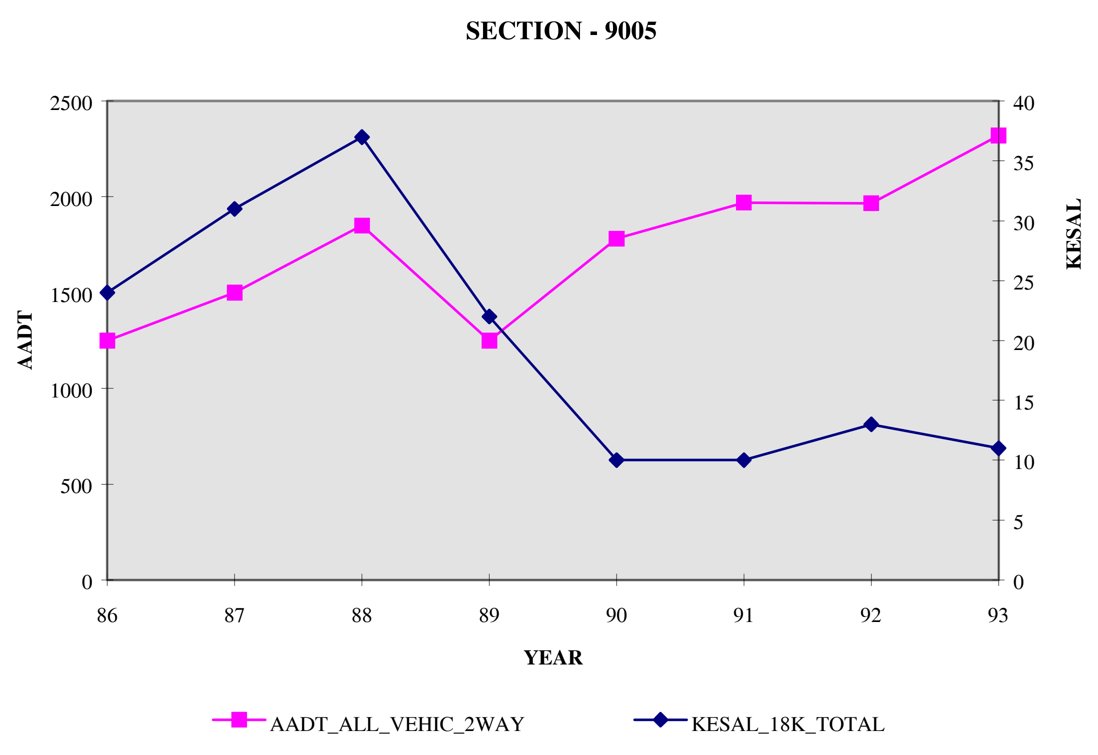


FIGURE B.16 Yearwise Variation of ADT and Annual Cumulative ESAL for Section 9005

APPENDIX C

OUTPUT FROM MODULUS PROGRAM

TABLE C.1 Summary Report for Section 1047

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) **(Version 5.1)**

District: 0
County: 0
Highway/Road: 1047

Thickness (in)
Pavement: 10.10
Base: 15.30
Subbase: 0.00
Subgrade: 120.30

MODULI RANGES (psi)

Minimum	Maximum
300,000	1,150,000
10,000	150,000
0	0
18,600	

Poisson Ratio Values
H1: õ = 0.35
H2: õ = 0.35
H3: õ = 0.30
H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,990	10.31	8.27	7.01	5.87	4.76	3.23	1.69	363	30.0	0.0	16.4	0.88	155.20
25.000	9,879	11.73	8.98	7.20	5.83	4.69	3.11	1.57	300	21.4	0.0	18.9	3.07	138.74
51.000	9,911	11.10	8.50	7.09	5.87	4.72	3.11	1.61	300	28.4	0.0	17.3	0.89	152.06
75.000	9,863	9.21	7.20	6.02	5.08	4.21	2.91	1.54	341	49.8	0.0	16.5	0.76	155.24
100.000	9,895	8.58	7.17	6.30	5.39	4.45	3.03	1.50	594	22.6	0.0	18.1	0.48	129.44
125.000	9,831	7.99	6.81	5.98	5.16	4.29	2.99	1.61	657	26.9	0.0	17.3	0.65	166.59
151.000	9,847	7.87	6.89	6.14	5.24	4.41	3.03	1.50	789	15.8	0.0	19.2	0.52	128.95
175.000	9,768	8.94	7.48	6.50	5.51	4.57	3.19	1.77	505	29.8	0.0	15.9	0.73	192.52
200.000	9,752	8.90	7.60	6.69	5.67	4.69	3.15	1.57	596	16.9	0.0	18.1	0.50	135.23
225.000	9,689	8.98	8.07	7.48	6.73	3.98	2.87	1.61	530	10.0	0.0	25.5	8.11	30.07
250.000	9,704	8.35	7.28	6.54	5.67	4.76	3.31	1.77	744	17.0	0.0	16.2	0.54	169.53
275.000	9,609	8.74	7.40	6.54	5.59	4.69	3.23	1.73	584	23.5	0.0	15.8	0.35	171.14
300.000	9,546	10.79	8.46	7.13	5.87	4.76	3.19	1.57	301	29.6	0.0	15.9	0.76	130.37
325.000	9,609	10.04	8.03	6.69	5.51	4.41	3.03	1.57	332	30.8	0.0	17.1	1.50	146.03
350.000	9,625	7.99	6.89	6.10	5.16	4.25	2.87	1.46	698	15.0	0.0	21.0	0.58	139.83
375.000	9,641	7.99	6.85	5.94	5.04	4.13	2.80	1.46	630	20.0	0.0	19.9	0.90	149.67
400.000	9,673	8.23	6.97	6.10	5.12	4.25	2.83	1.42	606	19.7	0.0	19.8	0.50	135.27
426.000	9,561	7.40	6.26	5.47	4.65	3.82	2.60	1.26	677	22.2	0.0	21.2	0.73	118.78
450.000	9,482	7.52	6.30	5.51	4.65	3.86	2.60	1.30	650	22.0	0.0	21.1	0.56	130.45
475.000	9,625	7.28	6.22	5.39	4.53	3.66	2.44	1.30	673	19.8	0.0	24.2	0.96	156.97
500.000	9,498	7.56	6.30	5.43	4.57	3.66	2.40	1.26	586	21.7	0.0	23.6	0.86	151.14
Mean:		8.83	7.33	6.35	5.37	4.33	2.95	1.53	546	23.5	0.0	19.0	1.18	145.67
Std. Dev:		1.28	0.80	0.62	0.54	0.37	0.26	0.16	158	8.2	0.0	2.9	1.69	101.74
Var Coeff(%):		14.48	10.98	9.81	10.05	8.56	8.88	10.16	29	35.0	0.0	15.2	142.56	69.84

TABLE C.2 Summary Report for Section 1050

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 1050

	Thickness (in)	MODULI RANGES (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	1.80	419,916	420,000	H1: õ = 0.35
Base:	16.10	10,000	150,000	H2: õ = 0.35
Subbase:	0.00	0	0	H3: õ = 0.35
Subgrade:	210.50	10,000		H4: õ = 0.40

Station	Load (lbs)	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
		R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	8,942	18.98	12.40	8.11	5.39	3.98	2.60	1.50	420	41.6	0.0	20.6	4.88	299.23
25.000	8,799	18.27	12.20	8.11	5.35	3.82	2.56	1.50	420	42.7	0.0	20.4	5.97	192.26
51.000	8,561	23.94	15.43	10.08	6.30	4.29	2.56	1.69	420	27.8	0.0	18.2	7.16	95.79
75.000	9,053	11.30	6.77	4.80	3.78	3.15	2.44	1.50	420	95.3	0.0	27.1	4.09	300.00
100.000	8,910	14.69	9.57	6.54	4.65	3.74	2.68	1.65	420	62.3	0.0	21.3	3.77	300.00
125.000	9,005	11.77	8.19	6.10	4.57	3.66	2.91	1.65	420	97.2	0.0	21.3	4.75	300.00
150.000	8,815	13.27	8.58	6.14	4.57	3.66	2.76	1.73	420	75.1	0.0	21.5	3.55	300.00
176.000	8,910	11.42	7.48	5.63	4.45	3.74	3.07	1.85	420	106.8	0.0	21.2	4.37	300.00
200.000	8,640	19.09	10.75	6.93	4.80	3.50	2.20	1.46	420	39.0	0.0	24.1	1.53	169.86
225.000	8,831	10.63	7.13	5.31	4.13	3.35	2.60	1.54	420	108.0	0.0	23.5	3.48	300.00
250.000	8,640	15.79	10.43	7.24	4.96	3.54	2.36	1.30	420	51.4	0.0	21.4	5.94	189.85
275.000	8,370	27.17	17.64	11.18	6.65	4.29	2.56	1.69	420	21.9	0.0	17.4	8.16	65.56
300.000	8,577	22.40	14.09	9.29	6.34	4.57	2.99	1.69	420	33.1	0.0	17.2	3.34	300.00
325.000	8,688	16.50	10.67	6.97	5.08	3.98	2.91	1.69	420	52.2	0.0	19.6	4.39	277.82
350.000	8,577	22.36	13.98	8.94	5.98	4.37	2.87	1.69	420	32.4	0.0	18.3	2.88	132.29
375.000	8,624	19.88	12.60	8.11	5.35	3.94	2.64	1.65	420	37.4	0.0	20.2	3.71	161.00
400.000	8,624	20.16	12.83	8.46	5.67	4.09	2.76	1.65	420	37.4	0.0	19.1	3.86	300.00
425.000	8,608	19.80	12.76	8.86	5.79	4.25	2.99	1.73	420	39.3	0.0	17.9	4.69	300.00
451.000	8,688	15.75	9.88	6.81	4.72	3.50	2.36	1.50	420	52.4	0.0	22.5	3.49	300.00
475.000	8,704	15.47	10.63	7.24	5.04	3.74	2.36	1.54	420	53.7	0.0	20.8	6.29	300.00
500.000	8,767	18.70	12.01	7.72	5.08	3.70	2.52	1.50	420	40.7	0.0	21.6	4.35	152.92
Mean:		17.49	11.24	7.55	5.17	3.85	2.65	1.60	420	54.6	0.0	20.7	4.51	228.42
Std. Dev:		4.47	2.80	1.60	0.75	0.36	0.24	0.13	0	26.3	0.0	2.4	1.51	141.85
Var Coeff(%):		25.56	24.95	21.12	14.45	9.45	9.09	7.80	0	48.2	0.0	11.6	33.54	62.10

TABLE C.3 Summary Report for Section 1060

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 1060

	Thickness (in)
Pavement:	7.50
Base:	12.30
Subbase:	0.00
Subgrade:	280.20

MODULI RANGES (psi)

Minimum	Maximum	Poisson Ratio Values
600,000	1,400,000	H1: õ = 0.35
250,000	5,000,000	H2: õ = 0.25
0	0	H3: õ = 0.30
10,000		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,736	4.88	4.37	4.09	3.66	2.99	2.56	1.77	1400	250.0	0.0	21.5	2.64	300.00
25.000	9,514	5.00	4.45	4.13	3.70	3.35	2.76	2.01	1400	284.0	0.0	18.7	0.54	300.00
50.000	9,530	5.79	5.24	4.84	4.37	3.90	3.15	2.20	1207	250.0	0.0	15.9	1.34	300.00
75.000	9,371	5.43	4.96	4.61	4.21	3.78	3.15	2.17	1400	286.8	0.0	15.3	0.99	300.00
100.000	9,323	5.24	4.76	4.37	4.02	3.58	3.03	2.13	1400	284.9	0.0	16.3	1.02	300.00
125.000	9,260	5.43	4.96	4.57	4.13	3.62	3.03	2.09	1332	250.0	0.0	16.3	1.42	300.00
150.000	9,291	5.16	4.72	4.45	3.98	3.58	2.99	2.17	1400	272.3	0.0	16.6	1.19	300.00
175.000	9,244	5.31	4.76	4.41	3.94	3.58	2.99	2.17	1400	258.7	0.0	16.7	0.78	300.00
200.000	9,196	5.12	4.53	4.29	3.90	3.58	2.99	2.13	1400	339.6	0.0	15.6	0.24	300.00
225.000	9,164	5.59	4.92	4.57	4.09	3.66	3.03	2.17	1137	250.0	0.0	16.5	0.56	300.00
250.000	9,148	4.65	4.25	3.94	3.54	3.19	2.72	2.05	1400	363.7	0.0	17.4	1.28	300.00
275.000	9,117	4.80	4.37	4.06	3.66	3.31	2.76	2.01	1400	331.2	0.0	17.1	0.99	300.00
300.000	9,133	4.29	3.74	3.54	3.23	2.91	2.56	1.89	1273	535.9	0.0	18.0	0.83	300.00
327.000	9,101	3.90	3.66	3.50	3.23	2.91	2.60	1.97	1400	915.7	0.0	15.1	2.36	300.00
350.000	9,069	4.13	3.74	3.46	3.19	2.95	2.60	1.97	1400	591.9	0.0	17.1	1.13	300.00
375.000	9,133	4.29	3.78	3.54	3.27	2.99	2.68	1.97	1205	681.7	0.0	16.5	0.97	300.00
400.000	9,037	4.65	4.21	3.94	3.58	3.23	2.76	2.05	1400	390.8	0.0	16.6	0.93	300.00
425.000	9,021	4.96	4.41	4.17	3.82	3.50	3.03	2.24	1340	422.6	0.0	14.6	0.47	300.00
450.000	9,053	5.63	5.04	4.65	4.25	3.82	3.15	2.24	1255	250.0	0.0	15.2	0.52	300.00
475.000	9,021	4.96	4.37	3.98	3.62	3.23	2.83	2.09	1029	384.7	0.0	17.1	1.37	300.00
500.000	9,101	5.59	4.76	4.45	4.02	3.43	3.03	2.17	898	290.7	0.0	16.9	1.70	300.00
Mean:		4.99	4.48	4.17	3.78	3.39	2.88	2.08	1308	375.5	0.0	16.7	1.11	300.00
Std. Dev:		0.53	0.46	0.41	0.36	0.31	0.20	0.12	142	173.0	0.0	1.5	0.59	0.00
Var Coeff(%):		10.56	10.32	9.85	9.43	9.23	7.13	5.81	11	46.1	0.0	8.8	53.12	0.00

TABLE C.4 Summary Report for Section 1068

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) Version (5.1)

District: 0
County: 0
Highway/Road: 1068

MODULI RANGES (psi)

	Thickness (in)	Minimum	Maximum	Poisson Ratio Values
Pavement:	10.90	200,000	560,000	H1: õ = 0.35
Base:	6.00	10,000	150,000	H2: õ = 0.35
Subbase:	0.00	0	0	H3: õ = 0.30
Subgrade:	128.20	18,700		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,355	8.11	6.34	5.47	4.61	3.78	2.56	1.42	385	59.4	0.0	20.1	0.50	186.82
25.000	9,434	8.70	6.65	5.79	4.88	3.98	2.60	1.38	355	50.5	0.0	19.8	0.70	162.77
50.000	9,371	8.94	6.97	5.94	5.04	4.06	2.64	1.34	364	31.2	0.0	20.0	0.69	141.08
75.000	9,339	9.57	7.24	6.26	5.24	4.25	2.72	1.38	302	44.8	0.0	18.7	0.80	143.98
100.000	9,339	9.76	7.56	6.42	5.43	4.29	2.68	1.46	331	18.7	0.0	20.1	0.99	157.94
125.000	9,339	10.04	7.56	6.46	5.43	4.29	2.72	1.34	281	36.0	0.0	18.9	0.86	132.30
150.000	9,260	9.49	7.17	6.10	5.12	4.09	2.72	1.38	288	50.9	0.0	18.8	0.70	138.98
176.000	9,260	7.95	6.38	5.59	4.80	3.94	2.64	1.38	478	30.7	0.0	19.6	0.50	152.45
200.000	9,164	9.53	7.40	6.30	5.31	4.29	2.83	1.42	314	39.1	0.0	18.0	0.62	137.66
225.000	9,164	8.86	7.01	5.94	5.04	4.09	2.76	1.38	353	43.3	0.0	18.5	0.95	132.95
250.000	9,180	8.15	6.69	5.83	4.96	4.06	2.72	1.38	488	18.7	0.0	19.4	0.55	139.50
275.000	9,085	8.35	6.89	6.02	5.16	4.25	2.87	1.50	489	18.2	0.0	18.1	0.53	155.91
300.000	9,133	9.57	7.72	6.57	5.51	4.41	2.83	1.42	360	15.2	0.0	19.0	0.90	140.69
325.000	9,164	9.53	7.91	6.89	5.83	4.80	3.15	1.54	417	14.4	0.0	16.7	0.75	132.56
350.000	9,037	11.57	9.37	8.07	6.85	5.43	3.50	1.73	305	12.3	0.0	15.0	1.15	141.68
375.000	9,021	13.78	10.79	8.90	7.13	5.51	3.31	1.73	201	10.0	0.0	16.2	1.28	124.29
400.000	9,053	10.79	8.74	7.44	6.18	4.88	3.07	1.50	316	10.0	0.0	18.1	1.10	134.45
425.000	9,069	8.90	6.65	5.75	4.92	4.02	2.72	1.50	288	92.6	0.0	17.8	0.62	189.06
451.000	9,037	7.05	5.55	4.72	3.98	3.31	2.32	1.42	405	96.4	0.0	21.2	1.10	300.00
475.000	9,037	6.77	5.51	4.69	3.94	3.23	2.28	1.42	475	65.0	0.0	22.0	1.49	300.00
500.000	9,005	7.87	6.26	5.39	4.49	3.66	2.44	1.46	414	34.5	0.0	20.8	0.55	288.82
Mean:		9.20	7.26	6.22	5.23	4.22	2.77	1.45	362	37.7	0.0	18.9	0.82	145.13
Std. Dev:		1.55	1.22	0.99	0.79	0.57	0.30	0.11	78	25.0	0.0	1.7	0.28	31.83
Var Coeff(%):		16.85	16.85	16.00	15.04	13.54	10.71	7.40	22	66.4	0.0	8.8	33.84	21.93

TABLE C.5 Summary Report for Section 1077

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 1077

	Thickness (in)	MODULI RANGES (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	5.10	150,000	500,000	H1: õ = 0.35
Base:	10.40	10,000	250,000	H2: õ = 0.35
Subbase:	0.00	0	0	H3: õ = 0.35
Subgrade:	273.20	25,700		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,577	10.00	7.52	6.02	4.88	3.98	2.87	1.89	339	124.6	0.0	22.6	1.68	300.00
25.000	9,530	10.04	7.72	6.10	4.88	3.94	2.87	1.89	390	109.1	0.0	22.7	2.27	300.00
50.000	9,466	8.94	6.38	5.20	4.25	3.50	2.68	1.73	253	182.8	0.0	24.9	2.42	300.00
75.000	9,450	9.33	6.77	5.47	4.45	3.66	2.72	1.73	277	156.1	0.0	24.0	2.01	300.00
100.000	9,387	9.57	7.17	5.91	5.00	4.21	2.72	1.77	366	137.3	0.0	21.7	2.14	187.24
125.000	9,339	11.50	9.09	7.36	5.94	4.76	3.35	1.89	465	80.2	0.0	18.6	1.25	173.90
150.000	9,403	9.21	6.42	5.04	3.98	3.31	2.36	1.61	246	141.6	0.0	27.5	1.98	300.00
175.000	9,323	9.41	6.77	5.35	4.33	3.39	2.24	1.46	350	103.9	0.0	27.0	1.10	224.22
200.000	9,355	8.50	5.94	4.76	3.90	3.23	2.44	1.50	234	195.2	0.0	27.1	2.49	300.00
225.000	9,244	8.78	6.10	4.84	3.90	3.23	2.32	1.46	239	160.7	0.0	27.5	1.77	300.00
250.000	9,244	9.65	6.57	5.00	3.90	3.19	2.40	1.57	206	131.0	0.0	27.9	3.49	300.00
276.000	9,276	9.92	7.05	5.59	4.53	3.66	2.68	1.61	242	132.2	0.0	23.9	1.97	300.00
300.000	9,260	9.25	6.38	5.04	3.74	3.23	2.56	1.46	216	150.9	0.0	27.3	4.46	300.00
325.000	9,228	9.41	6.46	5.20	4.21	3.50	2.60	1.57	198	173.1	0.0	25.0	2.17	300.00
350.000	9,212	8.78	5.94	4.76	3.90	3.19	2.36	1.54	202	187.5	0.0	27.4	1.99	300.00
375.000	9,260	9.17	6.18	4.84	3.98	3.35	2.40	1.69	185	183.1	0.0	26.9	2.00	300.00
400.000	9,212	9.33	6.34	5.08	4.02	3.19	2.32	1.50	231	134.8	0.0	27.5	1.61	300.00
425.000	9,180	9.49	6.65	5.04	3.94	3.19	2.36	1.50	240	120.2	0.0	27.7	3.23	300.00
450.000	9,196	9.92	6.81	5.35	4.29	3.46	2.56	1.57	207	135.3	0.0	25.3	2.35	300.00
475.000	9,228	10.00	7.17	5.63	4.57	3.70	2.72	1.61	244	129.1	0.0	23.5	2.25	214.17
500.000	9,180	9.21	6.93	5.43	4.25	3.43	2.52	1.57	364	112.8	0.0	25.3	2.70	300.00
Mean:		9.50	6.78	5.38	4.33	3.54	2.57	1.62	271	142.0	0.0	25.3	2.25	288.77
Std. Dev:		0.63	0.71	0.60	0.52	0.40	0.26	0.14	76	30.3	0.0	2.5	0.75	56.21
Var Coeff(%):		6.63	10.54	11.19	11.98	11.41	10.00	8.77	28	21.3	0.0	9.8	33.39	19.47

TABLE C.6 Summary Report for Section 1094

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 1094

	Thickness (in)	MODULI RANGES (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	1.90	1,374,860	1,375,140	H1: õ = 0.35
Base:	8.40	50,000	1,000,000	H2: õ = 0.25
Subbase:	0.00	0	0	H3: õ = 0.30
Subgrade:	66.70	10,000		H4: õ = 0.40

Station	Load (lbs)	Measured Deflection (mils) R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi) SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens	Depth To Bedrock
0.000	9,514	9.25	5.98	4.61	3.35	2.60	1.69	0.79	1375	180.3	0.0	25.6	6.99	189.82
26.000	9,561	6.85	4.45	3.31	2.40	1.69	1.02	0.51	1375	215.4	0.0	39.4	4.76	24.00
50.000	9,403	8.31	5.31	3.90	2.52	1.81	0.98	0.43	1375	138.5	0.0	36.5	2.95	24.00
76.000	9,355	10.24	6.81	4.88	3.19	2.24	1.34	0.55	1375	109.9	0.0	28.3	4.75	138.17
100.000	9,339	9.72	6.61	4.92	3.39	2.48	1.42	0.59	1375	136.9	0.0	26.2	3.49	134.06
125.000	9,260	9.33	6.54	5.08	3.70	2.80	1.81	0.83	1375	183.7	0.0	22.1	4.95	180.26
150.000	9,212	8.50	6.10	4.84	3.66	2.91	1.81	0.94	1375	239.3	0.0	21.4	4.11	273.06
175.000	9,196	9.06	6.42	5.04	3.66	2.80	1.81	0.83	1375	195.8	0.0	21.8	4.76	180.33
200.000	9,148	7.01	4.96	4.02	3.03	2.36	1.50	0.59	1375	300.8	0.0	26.0	4.44	127.70
225.000	9,148	5.12	3.78	3.19	2.60	2.17	1.42	0.67	1375	677.3	0.0	27.3	4.91	194.01
250.000	9,164	5.83	4.13	3.35	2.56	2.05	1.34	0.63	1375	410.0	0.0	30.3	5.34	191.36
275.000	9,148	7.99	5.75	4.53	3.35	2.60	1.69	0.83	1375	241.9	0.0	23.3	4.72	224.98
300.000	9,117	13.54	8.66	6.34	4.33	3.19	1.97	0.91	1375	84.6	0.0	20.0	6.05	186.81
325.000	9,069	5.24	3.46	2.87	2.32	1.89	1.38	0.67	1375	557.2	0.0	32.2	8.81	210.22
350.000	9,085	6.61	4.02	2.99	2.24	1.81	1.30	0.67	1375	253.0	0.0	36.8	11.35	263.53
375.000	9,085	8.31	5.59	4.25	3.03	2.28	1.50	0.71	1375	185.8	0.0	27.2	6.14	196.42
400.000	9,085	10.00	6.38	4.69	3.19	2.32	1.38	0.63	1375	118.1	0.0	27.5	5.03	176.06
425.000	9,037	11.42	6.93	4.84	2.95	2.01	1.10	0.47	1375	87.0	0.0	29.0	5.15	91.48
450.000	9,037	8.54	5.63	3.98	2.52	1.73	0.94	0.35	1375	118.0	0.0	35.3	3.67	24.00
475.000	9,101	6.10	3.78	2.60	1.61	1.02	0.47	0.12	1375	220.2	0.0	45.8	21.71	24.00
500.000	9,037	6.34	3.74	2.40	1.38	0.94	0.47	0.12	1375	213.0	0.0	45.8	28.91	16.00
Mean:		8.25	5.48	4.13	2.90	2.18	1.35	0.61	1375	231.7	0.0	29.9	7.28	77.03
Std. Dev:		2.11	1.36	1.00	0.71	0.57	0.41	0.22	0	150.3	0.0	7.5	6.37	88.32
Var Coeff(%):		25.62	24.84	24.24	24.57	26.32	30.26	36.79	0	64.8	0.0	25.2	87.48	114.66

TABLE C.7 Summary Report for Section 1096

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 1096

	Thickness (in)	MODULI RANGES (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	7.10	680,000	1,120,000	H1: õ = 0.35
Base:	8.10	50,000	500,000	H2: õ = 0.35
Subbase:	0.00	0	0	H3: õ = 0.35
Subgrade:	167.90	10,000		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,498	10.20	9.06	8.23	7.05	6.06	4.17	2.09	1097	50.0	0.0	13.2	0.62	122.72
25.000	9,514	8.27	7.56	6.97	6.02	5.24	3.78	2.05	1120	134.4	0.0	13.8	1.47	148.39
50.000	9,403	7.20	6.50	5.83	5.08	4.37	3.15	1.81	1120	131.7	0.0	17.2	1.18	190.48
75.000	9,244	7.36	6.50	6.02	5.08	4.57	3.19	1.81	1120	122.4	0.0	16.7	1.66	188.87
103.000	9,164	6.73	5.98	5.55	4.92	4.02	3.11	1.77	1120	202.5	0.0	16.3	1.69	156.17
125.000	9,117	8.19	7.32	6.73	5.87	5.08	3.62	1.97	1120	90.1	0.0	14.7	1.43	153.98
150.000	9,164	7.24	6.42	5.91	5.16	4.29	3.15	1.73	1120	140.1	0.0	16.4	1.20	144.27
175.000	9,085	7.64	6.81	6.18	5.16	4.41	3.35	1.81	1120	79.3	0.0	17.2	2.08	130.60
200.000	9,053	7.48	6.54	5.98	5.35	4.69	3.54	2.05	1012	215.7	0.0	13.8	0.34	201.83
225.000	9,053	6.89	6.14	5.63	4.96	4.29	3.19	1.85	1120	203.2	0.0	15.4	0.79	196.95
250.000	9,021	8.23	7.40	6.73	5.79	4.88	3.54	1.85	1120	89.9	0.0	14.6	0.86	126.44
275.000	9,005	8.90	8.03	7.44	6.10	5.16	3.58	1.93	1120	50.0	0.0	14.8	1.43	146.17
300.000	9,005	10.28	9.17	8.46	7.48	6.14	4.25	2.01	1050	50.0	0.0	12.0	1.56	107.23
326.000	8,990	6.54	5.75	5.12	4.53	3.78	2.64	1.54	1120	138.2	0.0	19.2	1.32	211.38
350.000	8,990	5.91	4.84	4.61	4.29	3.50	2.36	1.69	1120	163.7	0.0	21.6	3.63	300.00
377.000	9,005	6.30	5.35	5.08	4.33	3.70	2.60	1.73	1120	158.0	0.0	19.7	1.71	300.00
400.000	9,037	6.42	5.75	5.20	4.65	3.58	3.03	1.81	1120	199.6	0.0	17.5	3.54	300.00
425.000	9,005	6.89	6.02	5.47	4.88	3.82	2.99	1.57	1120	127.7	0.0	18.0	2.37	300.00
450.000	8,926	7.32	6.22	5.71	5.00	4.02	3.03	1.69	1120	83.5	0.0	18.3	2.36	146.88
475.000	8,910	8.03	6.97	6.38	5.94	4.69	3.46	1.81	1120	110.3	0.0	14.4	2.04	300.00
500.000	8,942	6.93	6.10	5.31	4.61	3.70	2.91	1.69	946	145.2	0.0	18.5	2.38	300.00
Mean:		7.57	6.69	6.12	5.35	4.48	3.27	1.82	1102	127.9	0.0	16.4	1.70	183.08
Std. Dev:		1.16	1.10	1.01	0.84	0.75	0.47	0.15	45	51.3	0.0	2.4	0.84	59.16
Var Coeff(%):		15.27	16.48	16.49	15.66	16.82	14.51	8.34	4	40.1	0.0	14.7	49.51	32.31

TABLE C.8 Summary Report for Section 1113

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 1113

	Thickness (in)
Pavement:	1.50
Base:	11.50
Subbase:	0.00
Subgrade:	32.10

MODULI RANGES (psi)

Minimum	Maximum	Poisson Ratio Values
699,930	700,070	H1: õ = 0.35
10,000	150,000	H2: õ = 0.35
0	0	H3: õ = 0.35
10,000		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,704	16.10	9.09	5.28	2.76	1.85	1.22	0.79	700	56.7	0.0	20.4	13.80	55.09
25.000	9,657	15.83	8.90	5.47	2.83	1.93	1.22	0.79	700	58.6	0.0	19.5	12.44	55.59
50.000	9,577	16.34	8.90	5.35	2.68	1.81	1.18	0.71	700	54.5	0.0	20.8	13.28	62.34
75.000	9,577	15.59	8.58	5.08	2.64	1.81	1.18	0.67	700	58.3	0.0	21.0	13.36	54.90
100.000	9,482	15.51	8.54	5.08	2.72	1.85	1.10	0.67	700	58.6	0.0	20.4	12.10	52.59
125.000	9,482	17.01	9.02	5.16	2.60	1.73	1.10	0.63	700	49.6	0.0	22.0	13.52	62.14
150.000	9,403	16.73	9.21	5.35	2.76	1.89	1.22	0.71	700	52.1	0.0	19.9	13.50	56.00
175.000	9,403	16.77	8.70	5.12	2.83	2.01	1.34	0.79	700	54.2	0.0	19.6	13.92	52.64
200.000	9,339	15.43	7.95	4.72	2.56	1.85	1.22	0.75	700	58.7	0.0	21.4	14.11	52.29
225.000	9,291	14.88	8.11	4.65	2.64	1.81	1.18	0.67	700	60.9	0.0	20.8	13.34	60.73
250.000	9,339	15.04	8.23	4.76	2.44	1.65	1.02	0.59	700	57.3	0.0	22.7	13.21	24.00
276.000	9,339	15.12	7.83	4.37	2.28	1.65	1.10	0.63	700	56.7	0.0	24.5	15.68	95.60
300.000	9,339	15.35	8.35	4.65	2.40	1.65	1.06	0.63	700	55.3	0.0	23.2	14.09	101.91
325.000	9,291	15.79	8.54	4.72	2.40	1.65	1.06	0.63	700	52.6	0.0	23.1	14.22	134.02
350.000	9,291	16.14	8.66	4.80	2.52	1.69	1.06	0.67	700	51.8	0.0	22.4	13.68	119.54
375.000	9,291	15.79	8.03	4.37	2.32	1.61	1.06	0.63	700	52.6	0.0	24.8	15.48	300.00
400.000	9,307	15.20	7.60	4.21	2.09	1.46	0.98	0.59	700	53.6	0.0	27.2	15.56	24.00
425.000	9,307	14.06	7.24	4.09	2.24	1.57	0.98	0.63	700	62.3	0.0	25.3	14.26	24.00
450.000	9,307	13.19	6.77	3.82	2.01	1.38	0.91	0.67	700	65.3	0.0	28.2	14.30	24.00
475.000	9,244	13.46	7.24	4.13	2.28	1.57	0.98	0.63	700	65.9	0.0	24.3	13.13	24.00
500.000	9,244	14.13	7.64	4.29	2.36	1.61	1.02	0.59	700	61.8	0.0	23.6	13.47	24.00
Mean:		15.40	8.24	4.74	2.49	1.72	1.10	0.67	700	57.0	0.0	22.6	13.83	45.07
Std. Dev:		1.03	0.67	0.48	0.24	0.16	0.11	0.06	0	4.5	0.0	2.4	0.92	26.56
Var Coeff(%):		6.70	8.17	10.06	9.55	9.26	9.76	9.63	0	7.8	0.0	10.8	6.63	58.93

TABLE C.9 Summary Report for Section 1130

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District:	0			MODULI RANGES (psi)		
County:	0		Thickness (in)	Minimum	Maximum	Poisson Ratio Values
Highway/Road:	1130	Pavement:	2.70	1,600,000	2,400,001	H1: õ = 0.35
		Base:	17.90	10,000	150,000	H2: õ = 0.35
		Subbase:	0.00	0	0	H3: õ = 0.35
		Subgrade:	279.40	10,000		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,895	17.09	12.32	9.61	7.01	5.28	3.50	1.97	1600	35.1	0.0	18.0	1.17	300.00
25.000	9,593	15.71	10.83	8.43	5.98	4.37	3.03	1.81	1600	36.4	0.0	21.0	2.79	300.00
50.000	9,530	15.83	10.87	8.31	5.71	4.37	3.07	1.89	1600	35.8	0.0	21.2	3.90	300.00
75.000	9,387	17.20	11.69	8.90	5.98	4.49	3.11	1.89	1600	29.7	0.0	21.0	4.64	300.00
101.000	9,403	14.96	11.06	8.86	6.34	4.80	3.07	1.81	1856	36.4	0.0	19.1	0.62	300.00
125.000	9,371	14.37	9.72	7.32	5.08	3.90	2.72	1.69	1600	39.9	0.0	23.4	3.89	300.00
150.000	9,228	16.06	10.39	7.72	5.16	3.90	2.72	1.73	1600	31.8	0.0	24.2	6.06	300.00
175.000	9,117	16.10	10.51	7.83	5.12	3.82	2.60	1.61	1600	29.8	0.0	24.7	5.66	300.00
200.000	9,148	14.88	10.31	7.72	5.08	3.82	2.64	1.61	1600	33.8	0.0	23.9	3.94	300.00
225.000	9,101	14.92	10.39	8.15	5.51	4.02	2.60	1.50	1600	33.5	0.0	22.6	1.70	300.00
250.000	9,133	15.75	10.71	7.83	5.04	3.70	2.60	1.57	1600	29.8	0.0	25.2	5.52	300.00
275.000	9,085	17.32	11.61	8.50	5.47	3.90	2.64	1.69	1600	24.9	0.0	24.5	5.84	216.01
301.000	9,117	15.39	10.67	7.95	5.24	3.82	2.68	1.77	1600	31.5	0.0	23.8	4.37	300.00
325.000	9,101	14.45	9.96	7.13	4.80	3.62	2.72	1.61	1600	36.2	0.0	24.5	6.08	300.00
351.000	9,085	15.28	10.98	8.15	5.35	4.06	2.91	1.81	1600	32.7	0.0	22.0	4.48	300.00
375.000	9,180	13.98	9.61	7.13	4.92	3.98	2.91	1.69	1600	42.5	0.0	22.1	4.82	300.00
400.000	9,164	12.80	9.09	6.85	4.84	3.70	2.80	1.81	1600	47.7	0.0	22.5	3.70	300.00
425.000	9,037	15.35	10.20	7.52	4.96	3.82	2.80	1.73	1600	33.4	0.0	23.6	6.43	300.00
450.000	9,085	15.55	10.31	7.32	4.72	3.62	2.68	1.77	1600	31.5	0.0	25.6	7.48	300.00
475.000	9,228	13.94	8.94	6.54	4.49	3.58	2.76	1.81	1600	42.8	0.0	24.9	7.40	300.00
500.000	8,990	14.96	9.57	7.20	5.00	3.90	2.87	1.81	1600	37.4	0.0	22.6	6.55	300.00
Mean:		15.33	10.46	7.86	5.32	4.02	2.83	1.74	1612	34.9	0.0	22.9	4.62	300.00
Std. Dev:		1.11	0.84	0.75	0.60	0.42	0.23	0.12	56	5.2	0.0	2.0	1.91	101.55
Var Coeff(%):		7.27	7.98	9.55	11.26	10.55	7.96	6.72	3	14.9	0.0	8.8	41.31	33.85

TABLE C.10 Summary Report for Section 1168

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 1168

Thickness (in)
Pavement: 1.20
Base: 10.40
Subbase: 0.00
Subgrade: 78.10

MODULI RANGES (psi)

	Minimum	Maximum
Pavement	224,977	225,023
Base	10,000	150,000
Subbase	0	0
Subgrade	10,000	

Poisson Ratio Values
H1: õ = 0.35
H2: õ = 0.35
H3: õ = 0.35
H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,037	30.24	15.91	8.54	5.55	3.70	2.28	1.26	225	28.3	0.0	18.0	7.53	0.00
25.000	9,164	26.85	14.13	7.44	5.12	3.62	2.24	1.14	225	33.7	0.0	19.9	8.87	0.00
52.000	8,720	44.76	23.50	10.67	5.43	3.35	1.85	1.14	225	14.9	0.0	14.9	11.89	0.00
77.000	8,974	31.85	18.82	11.18	7.09	4.65	2.56	1.14	225	29.2	0.0	13.7	5.22	53.65
102.000	9,037	27.60	15.43	9.45	6.02	4.13	2.52	1.30	225	35.0	0.0	16.0	6.41	61.30
127.000	9,053	25.08	14.29	8.62	5.39	3.66	2.20	1.18	225	38.2	0.0	17.8	6.77	55.21
152.000	8,958	29.65	17.17	9.88	6.34	4.37	2.44	1.18	225	31.2	0.0	15.1	6.07	60.27
177.000	8,910	33.82	19.92	11.97	8.15	5.39	2.99	1.42	225	28.5	0.0	11.9	4.66	55.28
202.000	8,910	32.56	18.98	11.65	7.60	5.12	2.83	1.42	225	29.4	0.0	12.6	4.58	63.47
225.000	8,926	26.81	14.76	8.78	5.87	3.98	2.28	1.34	225	35.3	0.0	16.7	5.36	53.36
252.000	8,926	25.94	14.21	7.91	5.12	3.35	1.93	1.18	225	33.9	0.0	19.3	6.49	106.22
277.000	9,085	21.14	11.46	6.61	4.13	2.72	1.50	0.83	225	42.8	0.0	24.4	5.56	58.31
302.000	9,037	23.46	12.20	6.73	4.33	2.91	1.69	0.91	225	37.1	0.0	23.3	6.45	150.91
327.000	8,958	24.13	12.60	6.93	4.29	2.87	1.69	0.87	225	35.0	0.0	22.9	6.93	177.94
352.000	8,958	27.24	13.70	7.56	4.57	3.03	1.65	0.83	225	29.8	0.0	21.5	5.13	149.60
376.000	9,228	17.56	7.80	4.65	3.19	2.28	1.38	0.71	225	52.3	0.0	34.5	8.24	52.76
400.000	9,260	17.24	8.86	5.16	3.66	2.60	1.61	0.83	225	58.3	0.0	28.9	7.66	54.72
425.000	9,037	25.94	14.06	8.46	5.63	3.82	2.24	1.10	225	37.0	0.0	17.6	5.53	54.74
452.000	8,640	38.11	20.59	11.06	6.61	4.57	2.68	1.38	225	20.6	0.0	13.8	7.27	0.00
477.000	8,799	36.46	20.63	11.69	7.48	4.76	2.64	1.38	225	23.5	0.0	13.0	5.34	72.71
488.000	8,847	31.54	17.24	9.53	6.02	3.98	2.32	1.22	225	26.9	0.0	16.1	6.68	139.61
Mean:		28.48	15.54	8.78	5.60	3.76	2.17	1.13	225	33.4	0.0	18.7	6.60	89.73
Std. Dev:		6.59	3.97	2.13	1.32	0.85	0.46	0.22	0	9.7	0.0	5.7	1.67	487.72
Var Coeff(%):		23.13	25.53	24.20	23.59	22.75	21.32	19.39	0	29.0	0.0	30.5	25.35	543.54

TABLE C.11 Summary Report for Section 1178

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 1178

	Thickness (in)	MODULI RANGES (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	8.50	270,000	700,000	H1: õ = 0.35
Base:	10.80	50,000	1,000,000	H2: õ = 0.25
Subbase:	0.00	0	0	H3: õ = 0.35
Subgrade:	280.70	10,000		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,434	7.48	6.54	5.87	5.08	4.17	2.87	1.61	700	61.4	0.0	20.4	2.55	202.10
25.000	9,434	6.22	5.43	4.88	4.33	3.74	2.99	2.05	700	166.3	0.0	19.4	1.47	300.00
50.000	9,371	5.35	4.41	3.86	3.35	2.91	2.32	1.57	678	208.8	0.0	25.3	1.27	300.00
75.000	9,355	6.22	5.35	4.72	4.09	3.46	2.60	1.54	700	92.2	0.0	23.8	1.66	222.35
100.000	9,260	6.06	5.04	4.49	3.98	3.43	2.76	1.81	640	197.5	0.0	20.4	0.93	300.00
125.000	9,212	5.47	4.65	4.13	3.66	3.23	2.60	1.81	700	212.5	0.0	21.9	1.26	300.00
150.000	9,228	6.22	5.24	4.69	4.13	3.62	2.95	2.01	658	200.6	0.0	18.9	1.06	300.00
175.000	9,180	5.59	4.61	4.06	3.62	3.19	2.72	1.81	562	327.1	0.0	20.3	1.83	300.00
200.000	9,085	5.20	4.17	3.62	3.23	2.87	2.32	1.69	542	320.7	0.0	24.0	1.22	300.00
226.000	9,085	5.28	4.37	3.82	3.35	2.91	2.32	1.61	677	211.3	0.0	24.2	1.18	300.00
250.000	9,117	5.43	4.37	3.86	3.39	2.95	2.44	1.69	547	284.7	0.0	23.1	1.37	300.00
275.000	9,037	4.80	4.02	3.54	3.15	2.80	2.28	1.57	700	248.7	0.0	24.9	1.95	300.00
300.000	9,037	4.53	3.66	3.23	2.83	2.48	2.09	1.46	643	365.1	0.0	26.7	1.73	300.00
325.000	9,005	5.63	4.65	3.98	3.39	2.91	2.20	1.46	664	126.0	0.0	26.6	1.29	300.00
350.000	9,037	6.69	5.51	4.76	4.06	3.39	2.56	1.61	582	94.6	0.0	23.1	1.08	300.00
375.000	9,021	6.18	5.04	4.37	3.70	3.07	2.36	1.50	604	105.9	0.0	25.3	1.31	300.00
400.000	9,101	4.13	3.43	3.07	2.76	2.48	2.09	1.50	700	589.5	0.0	24.7	1.21	300.00
425.000	9,021	4.45	3.62	3.23	2.91	2.60	2.13	1.54	700	270.0	0.0	27.8	3.00	300.00
450.000	9,021	4.80	4.02	3.50	3.11	2.76	2.24	1.54	700	250.2	0.0	25.3	1.85	300.00
475.000	8,894	6.61	5.24	4.53	3.90	3.27	2.52	1.61	469	130.1	0.0	22.9	1.06	300.00
500.000	9,005	5.51	4.41	3.86	3.43	2.95	2.36	1.61	545	241.7	0.0	23.6	1.05	300.00
Mean:		5.61	4.66	4.10	3.59	3.10	2.46	1.65	639	224.0	0.0	23.5	1.49	300.00
Std. Dev:		0.83	0.75	0.67	0.56	0.43	0.27	0.16	71	118.1	0.0	2.5	0.52	35.82
Var Coeff(%):		14.76	16.10	16.43	15.62	13.73	11.16	10.01	11	52.7	0.0	10.5	34.89	11.94

TABLE C.12 Summary Report for Section 3579

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 3579

	Thickness (in)
Pavement:	1.70
Base:	10.80
Subbase:	9.20
Subgrade:	278.30

MODULI RANGES (psi)

Minimum	Maximum	Poisson Ratio Values
149,985	150,015	H1: õ = 0.35
50,000	1,000,000	H2: õ = 0.25
25,000	1,000,000	H3: õ = 0.25
26,200		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,927	12.17	7.28	5.28	4.37	3.78	2.76	1.50	150	100.4	161.2	24.5	1.84	300.00
25.000	9,863	12.83	7.20	5.59	4.96	4.33	3.19	1.73	150	90.7	400.0	20.0	1.93	300.00
50.000	9,879	11.77	6.81	5.28	4.61	3.98	3.03	1.81	150	104.3	336.6	21.7	0.99	300.00
75.000	9,784	12.36	7.28	5.31	4.49	3.90	2.99	1.77	150	92.9	264.7	22.3	1.72	300.00
100.000	9,768	13.46	8.07	5.59	4.53	3.86	2.91	1.69	150	83.0	137.6	23.2	3.02	300.00
125.000	9,736	10.75	5.79	4.45	3.74	3.31	2.56	1.57	150	99.9	676.7	24.9	0.34	300.00
150.000	9,800	11.73	5.79	4.25	3.82	3.46	2.72	1.69	150	86.0	1000.0	23.8	3.05	300.00
175.000	9,768	10.08	5.51	4.02	3.46	3.07	2.36	1.46	150	106.0	730.8	27.1	1.29	300.00
200.000	9,816	9.76	5.04	3.66	3.11	2.72	2.17	1.38	150	103.6	1000.0	29.5	1.26	300.00
225.000	9,784	9.72	5.71	4.37	3.78	3.31	2.52	1.50	150	130.8	357.9	26.2	1.09	300.00
250.000	9,704	10.71	5.91	4.41	3.70	3.19	2.52	1.50	150	101.0	483.1	26.0	1.30	300.00
275.000	9,673	10.83	5.79	4.29	3.66	3.15	2.36	1.46	150	96.6	487.0	26.7	1.11	300.00
300.000	9,641	12.83	6.54	4.57	3.82	3.23	2.52	1.46	150	70.2	701.3	24.2	1.39	300.00
325.000	9,641	9.29	5.00	3.98	3.35	2.91	2.20	1.30	150	125.1	474.0	29.2	0.55	300.00
351.000	9,673	10.35	5.51	3.94	3.35	2.95	2.28	1.42	150	97.2	721.6	27.7	1.22	300.00
375.000	9,673	10.39	5.59	4.25	3.70	3.19	2.44	1.50	150	104.7	598.4	26.0	0.95	300.00
400.000	9,673	9.45	5.31	4.02	3.35	2.91	2.20	1.34	150	124.5	330.7	29.8	0.96	300.00
425.000	9,593	14.33	7.32	4.72	3.50	2.87	2.13	1.22	150	62.5	164.1	31.5	2.87	165.42
450.000	9,641	12.80	6.57	4.57	3.62	3.11	2.40	1.50	150	71.6	433.8	26.6	1.66	300.00
475.000	9,657	11.65	5.83	4.09	3.27	2.76	2.01	1.30	150	81.2	337.4	31.3	0.69	300.00
500.000	9,609	10.39	5.31	3.82	3.03	2.52	1.85	1.14	150	94.2	310.4	33.4	0.70	300.00
Mean:		11.32	6.15	4.50	3.77	3.26	2.48	1.49	150	96.5	481.3	26.5	1.42	300.00
Std. Dev:		1.42	0.88	0.59	0.53	0.47	0.35	0.18	0	17.5	249.4	3.4	0.77	50.04
Var Coeff(%):		12.56	14.23	13.04	13.98	14.40	14.16	11.98	0	18.2	51.8	13.0	53.90	16.68

TABLE C.13 Summary Report for Section 3729

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 3729

	Thickness (in)	MODULI RANGES (psi)		Poisson Ratio Values
		Minimum	Maximum	
Pavement:	10.00	1,375,000	1,800,000	H1: õ = 0.35
Base:	10.00	50,000	1,000,000	H2: õ = 0.25
Subbase:	12.00	10,000	250,000	H3: õ = 0.25
Subgrade:	268.00	10,000		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,768	5.59	5.16	4.88	4.53	4.13	3.43	2.44	1800	139.3	15.5	15.2	0.34	300.00
25.000	9,816	5.12	4.69	4.41	3.98	3.62	2.99	2.13	1800	95.9	19.5	19.4	0.74	300.00
50.000	9,720	5.63	5.20	5.00	4.37	3.86	3.43	2.20	1467	97.5	49.9	13.8	2.36	300.00
76.000	9,530	5.00	4.61	4.41	4.09	3.78	3.11	2.24	1800	154.8	16.9	16.8	1.30	300.00
100.000	9,625	4.57	4.29	4.06	3.74	3.46	2.91	2.09	1800	332.4	16.1	16.1	1.06	300.00
125.000	9,450	4.61	4.06	3.94	3.74	3.19	3.11	2.09	1375	243.6	250.0	10.1	2.51	300.00
152.000	9,403	4.25	3.82	3.54	3.31	3.07	2.68	2.01	1414	435.4	46.1	15.4	0.66	300.00
175.000	9,387	4.37	4.02	3.66	3.54	3.11	2.80	2.01	1582	336.8	43.4	15.1	1.93	300.00
200.000	9,387	4.65	4.41	4.17	3.74	3.46	2.83	2.01	1800	177.7	17.8	17.8	1.39	300.00
225.000	9,276	5.31	4.88	4.57	4.21	3.66	3.19	2.09	1595	97.8	36.1	14.8	1.47	300.00
250.000	9,276	5.24	4.76	4.45	4.02	3.66	3.07	2.20	1423	123.0	41.5	14.8	0.68	300.00
275.000	9,276	5.20	4.45	4.29	3.98	3.46	3.07	2.01	1375	88.7	152.8	12.4	1.86	300.00
300.000	9,212	4.92	4.45	4.25	3.82	3.43	2.80	1.97	1800	85.9	19.9	19.1	0.51	300.00
325.000	9,196	5.55	5.12	4.76	4.33	3.90	3.15	2.17	1632	66.7	17.4	17.1	0.41	300.00
350.000	9,180	5.63	5.04	4.72	4.33	3.70	3.03	2.17	1375	50.0	37.2	16.7	0.96	300.00
375.000	9,196	4.76	4.37	3.78	3.39	3.15	2.72	1.77	1375	66.1	250.0	14.0	2.54	300.00
400.000	9,180	5.12	4.61	4.37	3.90	3.50	2.99	2.13	1390	128.7	39.9	15.4	1.12	300.00
425.000	9,180	5.00	4.57	4.33	3.94	3.62	3.03	2.09	1775	158.8	16.6	16.3	0.44	300.00
451.000	9,164	5.98	5.39	5.12	4.61	4.13	3.35	2.36	1424	50.0	31.8	14.7	0.38	300.00
475.000	9,212	5.16	4.72	4.49	4.25	3.94	3.43	2.52	1624	281.8	48.0	10.9	0.31	300.00
500.000	9,133	6.30	5.91	5.59	5.31	4.84	4.13	3.03	1800	54.2	90.8	8.7	0.76	300.00
Mean:		5.14	4.69	4.42	4.05	3.65	3.11	2.18	1592	155.5	59.9	15.0	1.13	300.00
Std. Dev:		0.52	0.49	0.49	0.45	0.41	0.32	0.26	183	108.8	70.6	2.7	0.73	0.00
Var Coeff(%):		10.12	10.54	11.18	11.15	11.22	10.44	11.74	12	70.0	100.0	18.1	64.91	0.00

TABLE C.14 Summary Report for Section 3739

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District:	0			MODULI RANGES (psi)		
County:	0		Thickness (in)	Minimum	Maximum	Poisson Ratio Values
Highway/Road:	3739	Pavement:	1.80	649,935	650,065	H1: õ = 0.35
		Base:	11.40	10,000	150,000	H2: õ = 0.35
		Subbase:	0.00	0	0	H3: õ = 0.25
		Subgrade:	244.20	10,000		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,418	23.15	17.99	14.53	10.24	7.36	4.17	2.28	650	47.0	0.0	12.1	9.15	136.79
25.000	9,530	23.82	16.61	12.91	9.92	7.44	4.45	2.40	650	48.4	0.0	12.6	3.43	207.34
50.000	9,403	24.41	18.43	14.37	9.80	6.97	4.06	2.28	650	40.5	0.0	12.5	8.30	164.18
75.000	9,482	21.54	16.89	12.91	9.25	7.01	4.53	2.28	650	54.8	0.0	12.7	5.41	278.93
100.000	9,482	19.02	15.39	11.73	7.87	5.67	3.94	2.20	650	59.1	0.0	14.9	7.82	240.77
125.000	9,434	19.69	15.35	12.17	8.90	6.65	4.13	2.20	650	62.6	0.0	13.4	6.40	300.00
150.000	9,434	16.77	13.39	10.94	8.23	6.22	3.94	2.20	650	83.9	0.0	14.2	6.39	300.00
175.000	9,450	13.19	9.76	7.91	6.30	5.39	4.17	2.48	650	140.9	0.0	16.4	3.30	300.00
200.000	9,355	14.29	11.34	9.57	7.68	6.18	4.13	2.24	650	124.9	0.0	13.9	3.34	300.00
225.000	9,387	16.46	12.17	9.92	7.64	6.06	4.17	2.24	650	90.3	0.0	14.7	1.91	300.00
250.000	9,466	13.46	10.67	8.70	6.89	5.63	3.82	2.09	650	129.6	0.0	15.7	2.69	300.00
275.000	9,403	21.81	16.18	12.01	8.11	5.94	3.82	2.09	650	45.6	0.0	14.6	5.76	300.00
300.000	9,403	22.95	15.16	11.22	7.20	5.00	3.50	2.09	650	38.1	0.0	17.1	4.33	119.73
325.000	9,228	27.52	19.57	14.45	9.06	6.18	3.58	1.89	650	28.2	0.0	13.9	7.80	99.73
350.000	9,418	17.56	12.95	10.12	7.20	5.43	3.62	2.09	650	68.1	0.0	16.4	4.38	300.00
375.000	9,339	13.35	9.80	7.87	6.10	4.84	3.50	2.01	650	114.5	0.0	18.3	2.22	300.00
400.000	9,244	13.03	10.00	8.07	6.34	5.12	3.66	2.17	650	125.9	0.0	16.9	2.16	300.00
425.000	9,387	12.72	8.98	7.24	5.71	4.84	3.62	2.20	650	131.8	0.0	18.9	2.76	300.00
450.000	9,307	13.98	10.75	8.62	6.57	5.16	3.54	2.09	650	105.9	0.0	17.0	3.26	300.00
475.000	9,276	22.20	16.50	12.80	8.90	6.18	3.70	2.05	650	44.5	0.0	13.8	8.17	124.13
500.000	9,387	12.91	9.57	7.80	6.14	5.12	3.58	2.24	650	130.6	0.0	17.6	1.23	300.00
Mean:		18.28	13.69	10.76	7.81	5.92	3.89	2.18	650	81.7	0.0	15.1	4.77	257.41
Std. Dev:		4.70	3.36	2.40	1.38	0.81	0.31	0.13	0	38.4	0.0	2.0	2.44	141.25
Var Coeff(%):		25.70	24.55	22.32	17.72	13.73	8.08	6.08	0	47.0	0.0	13.4	51.21	54.87

TABLE C.15 Summary Report for Section 3875

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) **(Version 5.1)**

District: 0
County: 0
Highway/Road: 3875

	Thickness (in)	MODULI RANGES (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	1.60	3,849,611	3,850,391	H1: õ = 0.35
Base:	16.70	50,000	1,000,000	H2: õ = 0.25
Subbase:	0.00	0	0	H3: õ = 0.35
Subgrade:	211.90	35,600		H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,800	7.91	5.47	3.86	2.64	1.89	1.26	0.75	3850	98.5	0.0	45.3	4.00	194.54
25.000	9,689	8.03	5.47	3.90	2.72	2.05	1.26	0.71	3850	97.8	0.0	43.0	3.35	235.03
50.000	9,593	8.74	5.91	4.17	2.91	2.05	1.42	0.79	3850	86.4	0.0	40.7	2.89	143.93
75.000	9,418	7.91	5.39	3.90	2.76	2.01	1.34	0.75	3850	98.6	0.0	40.6	3.28	285.02
100.000	9,466	7.99	5.98	4.29	2.72	1.77	0.98	0.59	3850	81.3	0.0	48.1	10.92	24.00
125.000	9,355	7.01	4.92	3.50	2.44	1.77	1.06	0.59	3850	107.2	0.0	47.4	5.77	183.83
150.000	9,307	7.09	4.84	3.54	2.48	1.81	1.26	0.71	3850	112.1	0.0	43.5	3.30	295.88
175.000	9,180	8.27	5.83	4.06	2.60	1.81	1.22	0.75	3850	80.8	0.0	44.6	4.51	119.95
200.000	9,196	7.36	5.16	3.70	2.64	1.97	1.34	0.79	3850	106.9	0.0	39.8	3.21	300.00
225.000	9,196	7.99	5.71	4.17	2.91	2.13	1.34	0.75	3850	93.5	0.0	37.5	5.16	299.18
250.000	9,117	7.64	5.83	4.41	3.11	2.24	1.46	0.83	3850	102.4	0.0	33.2	7.32	224.42
275.000	9,069	7.83	5.94	4.57	3.23	2.20	1.46	0.91	3850	96.6	0.0	32.9	8.37	92.97
300.000	9,053	7.17	5.31	4.06	2.91	2.20	1.46	0.91	3850	115.9	0.0	34.1	5.33	300.00
325.000	9,005	7.44	5.39	4.09	2.99	2.28	1.61	0.94	3850	114.4	0.0	32.4	3.43	300.00
350.000	8,942	7.83	5.63	4.17	2.99	2.24	1.57	0.94	3850	100.7	0.0	32.8	3.42	300.00
375.000	8,894	8.03	5.63	4.09	2.91	2.17	1.50	0.91	3850	94.0	0.0	34.6	2.73	300.00
400.000	8,926	7.13	5.08	3.74	2.72	1.97	1.42	0.87	3850	111.5	0.0	36.6	3.93	250.08
425.000	8,863	6.85	4.92	3.58	2.60	1.97	1.38	0.83	3850	117.3	0.0	37.3	3.31	300.00
450.000	8,942	6.81	4.96	3.66	2.64	2.01	1.42	0.87	3850	121.4	0.0	36.6	3.65	300.00
475.000	8,926	7.01	5.00	3.70	2.64	2.05	1.50	0.94	3850	118.5	0.0	35.8	3.12	300.00
500.000	8,910	8.15	5.71	4.17	2.95	2.28	1.69	1.14	3850	96.6	0.0	32.3	3.01	300.00
Mean:		7.63	5.43	3.97	2.79	2.04	1.38	0.82	3850	102.5	0.0	38.5	4.48	230.16
Std. Dev:		0.53	0.38	0.29	0.21	0.17	0.17	0.13	0	11.9	0.0	5.1	2.09	308.22
Var Coeff(%):		6.96	6.94	7.42	7.42	8.21	12.29	15.53	0	11.6	0.0	13.4	46.77	133.92

TABLE C.16 Summary Report for Section 9005

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 0
County: 0
Highway/Road: 9005

	Thickness (in)
Pavement:	1.50
Base:	9.40
Subbase:	0.00
Subgrade:	186.60

MODULI RANGES (psi)

Minimum	Maximum
1,299,870	1,300,130
50,000	1,000,000
0	0
27,300	

Poisson Ratio Values
H1: õ = 0.35
H2: õ = 0.25
H3: õ = 0.35
H4: õ = 0.40

Station	Load	Measured Deflection (mils)							Calculated Moduli values (ksi)				Absolute	Depth To
	(lbs)	R1	R2	R3	R4	R5	R6	R7	SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	ERR/Sens	Bedrock
0.000	9,466	10.28	6.97	5.39	3.90	2.91	1.65	0.55	1300	125.1	0.0	32.0	3.01	104.40
25.000	9,498	8.15	5.35	4.06	2.87	2.13	1.06	0.39	1300	145.3	0.0	44.7	5.55	77.00
50.000	9,418	10.83	6.61	4.69	2.95	2.01	0.98	0.35	1300	80.5	0.0	45.3	7.65	24.00
75.000	9,355	9.88	6.38	4.80	3.23	2.20	1.02	0.35	1300	99.4	0.0	41.3	9.26	24.00
100.000	9,323	10.00	6.65	5.04	3.27	2.17	0.98	0.35	1300	94.9	0.0	40.9	11.75	24.00
125.000	9,339	10.47	6.46	4.80	3.23	2.24	1.22	0.47	1300	94.5	0.0	39.9	4.68	103.00
150.000	9,260	8.07	5.12	3.90	2.68	1.89	0.94	0.28	1300	131.0	0.0	47.9	6.50	24.00
175.000	9,260	8.35	5.47	4.21	2.99	2.20	1.22	0.47	1300	143.7	0.0	41.3	3.37	111.84
200.000	9,180	8.94	5.71	4.41	3.23	2.48	1.50	0.59	1300	142.3	0.0	37.1	0.38	128.30
225.000	9,228	11.06	8.07	6.65	5.39	4.45	3.23	1.81	1300	193.3	0.0	19.2	2.96	300.00
250.000	9,180	10.59	7.48	6.22	5.12	4.37	3.35	2.01	1300	222.1	0.0	19.6	5.17	300.00
276.000	9,148	10.91	7.64	6.22	5.04	4.25	3.07	1.73	1300	185.4	0.0	20.6	4.31	300.00
300.000	9,196	12.72	8.86	6.97	5.31	4.21	2.87	1.50	1300	120.4	0.0	21.1	1.96	300.00
325.000	9,117	14.02	10.31	8.43	6.69	5.43	3.74	1.97	1300	131.2	0.0	15.7	1.42	300.00
350.000	9,117	9.72	7.01	5.83	4.76	3.98	2.91	1.69	1300	230.1	0.0	21.4	3.49	300.00
375.000	9,069	15.35	10.98	8.70	6.73	5.43	3.98	2.20	1300	106.9	0.0	15.7	3.30	300.00
400.000	9,101	13.70	9.33	7.44	5.87	4.92	3.31	1.85	1300	121.1	0.0	18.4	3.71	300.00
425.000	9,101	15.39	10.39	8.03	6.14	5.12	3.54	1.93	1300	96.3	0.0	17.7	4.09	300.00
450.000	9,021	12.99	9.53	7.87	6.34	5.28	3.82	2.09	1300	157.6	0.0	15.7	2.79	300.00
475.000	9,069	13.50	9.53	7.64	5.83	4.72	3.27	1.69	1300	119.1	0.0	18.4	2.18	289.24
500.000	9,053	10.39	7.72	6.34	4.92	3.86	2.56	1.14	1300	169.9	0.0	22.1	1.07	169.24
Mean:		11.21	7.69	6.08	4.59	3.63	2.39	1.21	1300	138.6	0.0	28.4	4.22	197.50
Std. Dev:		2.24	1.78	1.53	1.40	1.31	1.13	0.73	0	41.7	0.0	11.8	2.75	240.83
Var Coeff(%):		19.97	23.14	25.18	30.40	36.06	47.46	60.59	0	30.1	0.0	41.7	65.19	121.94

APPENDIX D

TREND ANALYSES

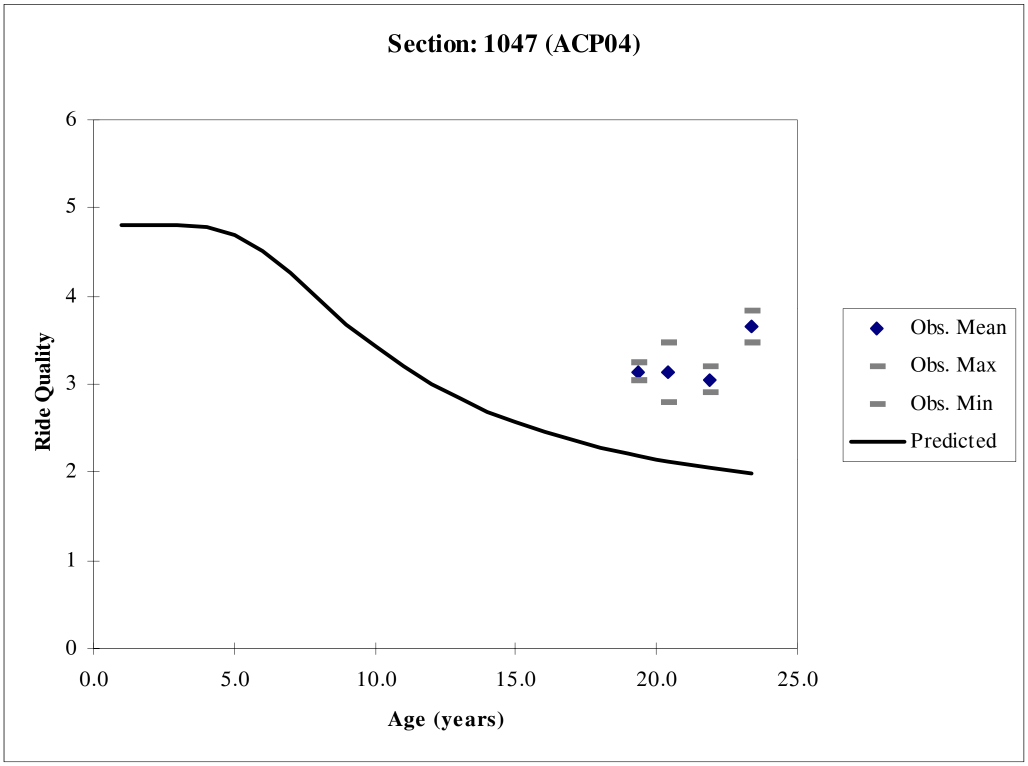


FIGURE D.1 Roughness Observed Versus Predicted for Section 1047 using TxDOT-PMIS Model

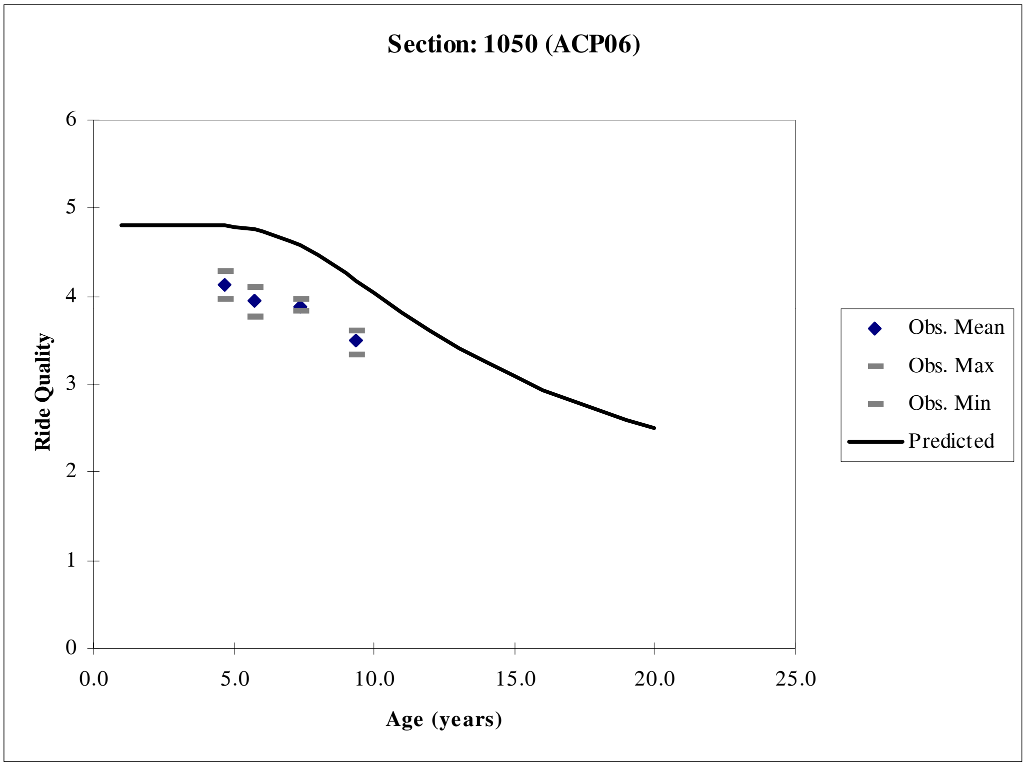


FIGURE D.2 Roughness Observed Versus Predicted for Section 1050 using TxDOT-PMIS Model

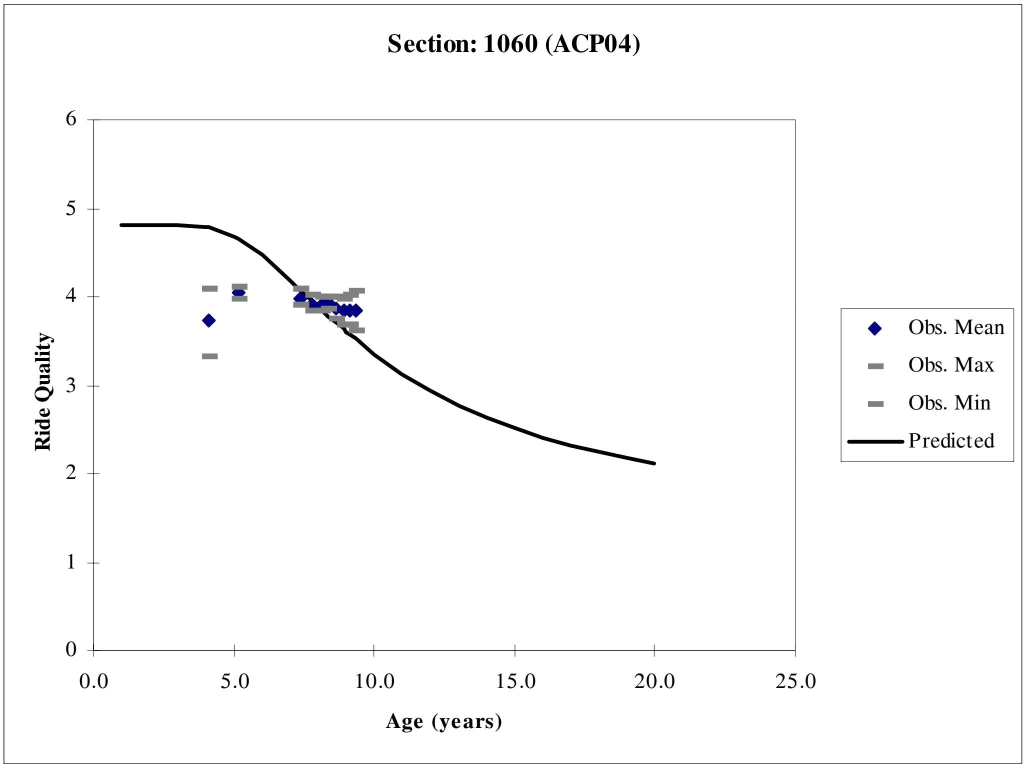


FIGURE D.3 Roughness Observed Versus Predicted for Section 1060 using TxDOT-PMIS Model

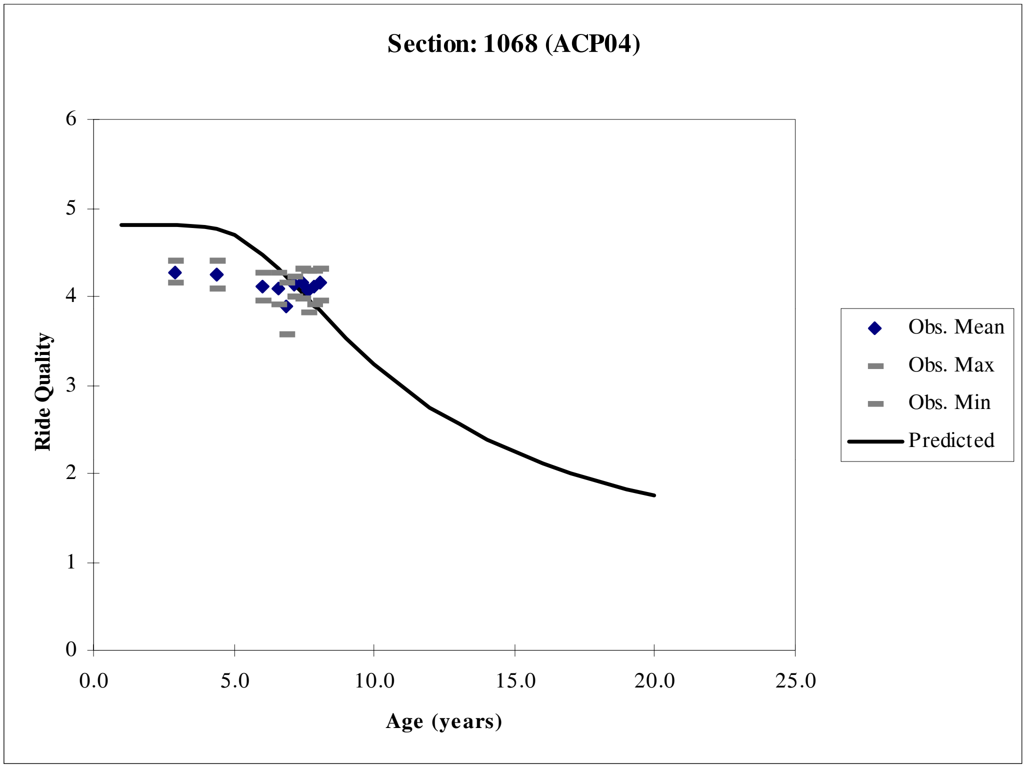


FIGURE D.4 Roughness Observed Versus Predicted for Section 1068 using TxDOT-PMIS Model

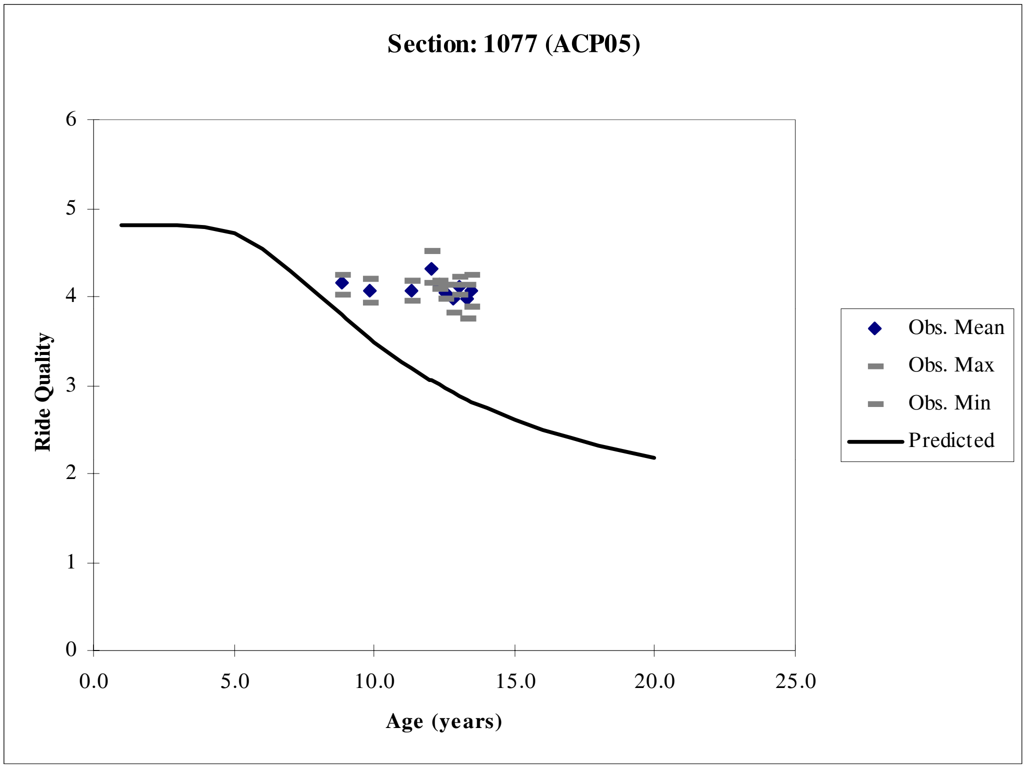


FIGURE D.5 Roughness Observed Versus Predicted for Section 1077 using TxDOT-PMIS Model

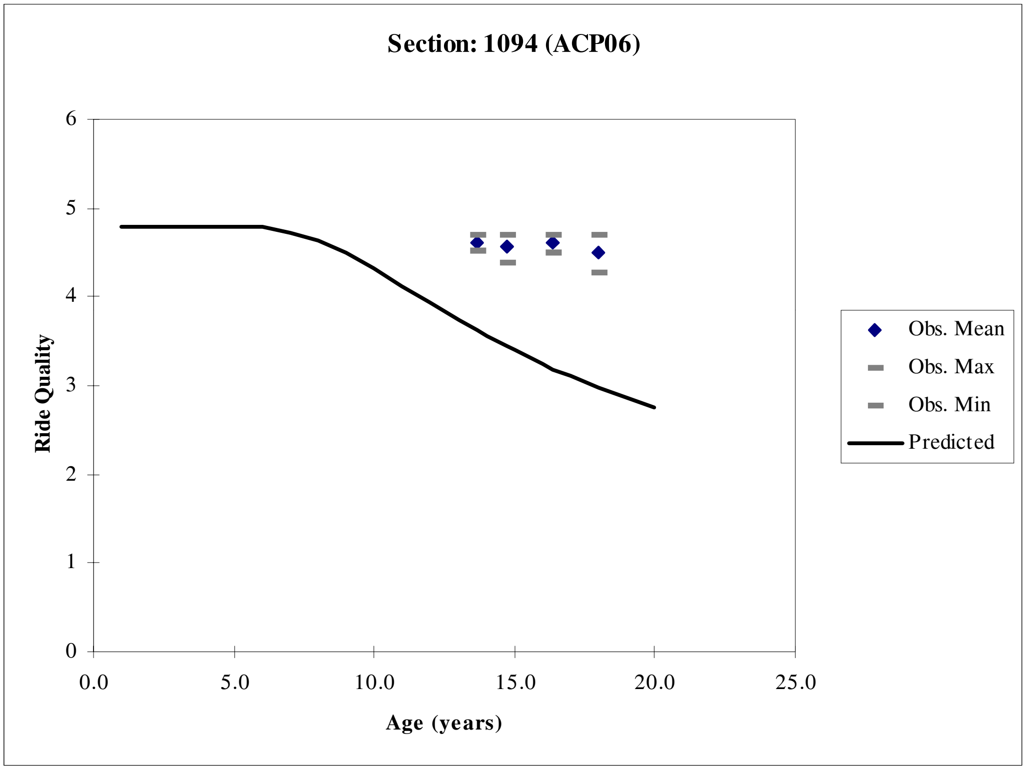


FIGURE D.6 Roughness Observed Versus Predicted for Section 1094 using TxDOT-PMIS Model

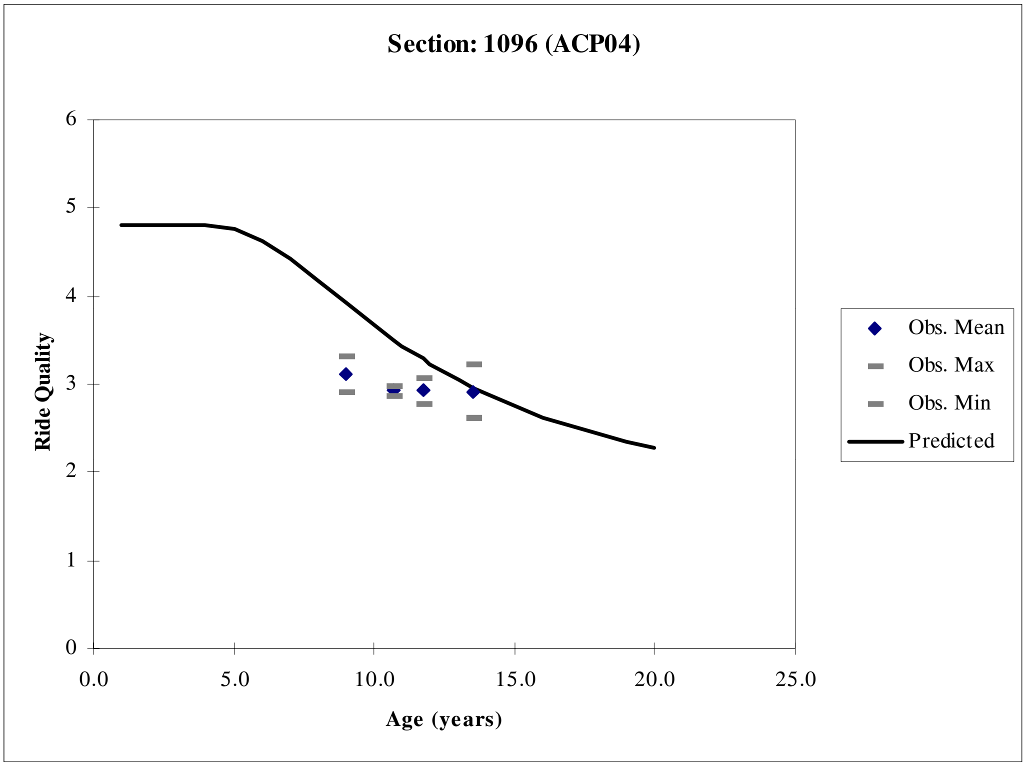


FIGURE D.7 Roughness Observed Versus Predicted for Section 1096 using TxDOT-PMIS Model

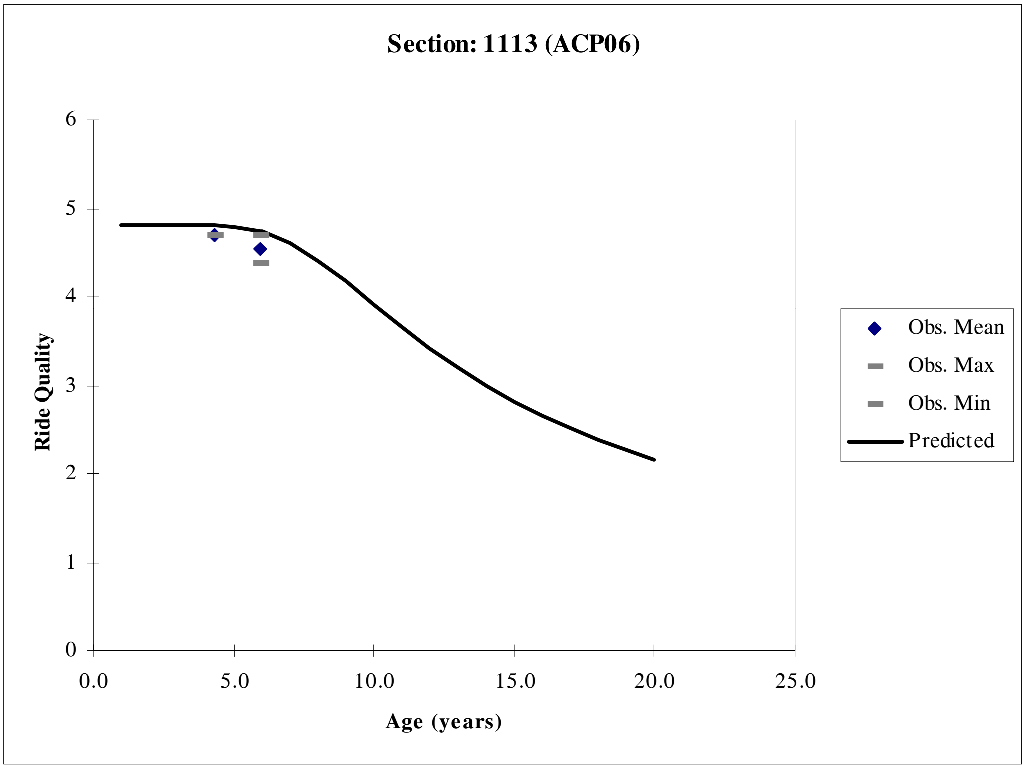


FIGURE D.8 Roughness Observed Versus Predicted for Section 1113 using TxDOT-PMIS Model

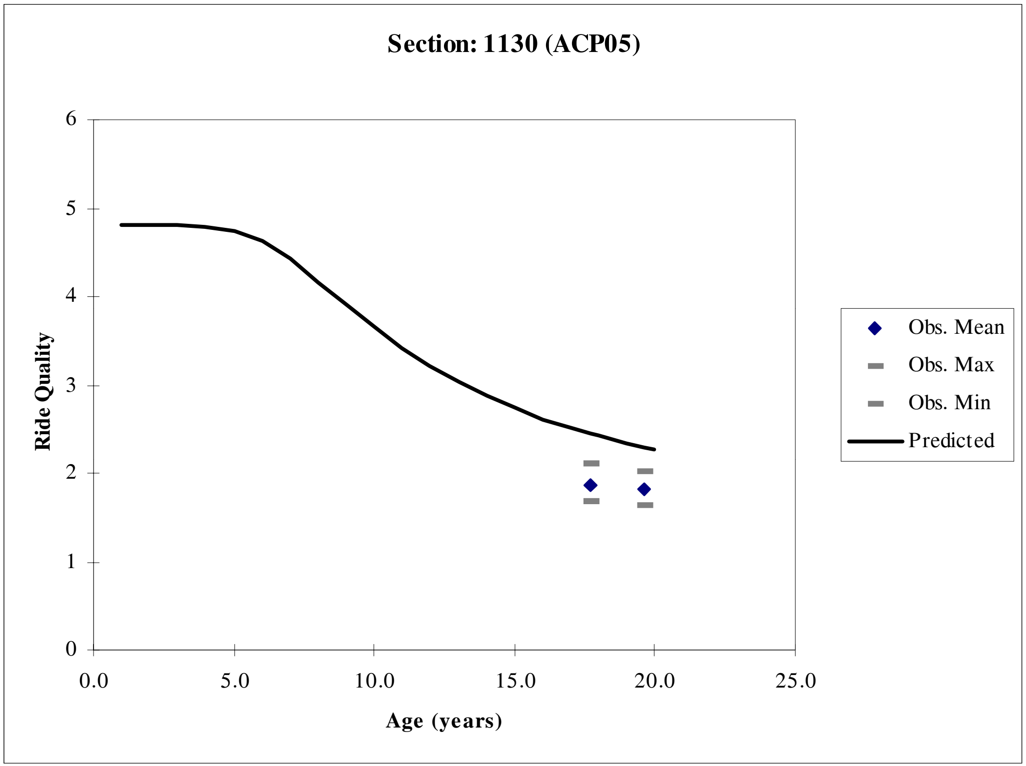


FIGURE D.9 Roughness Observed Versus Predicted for Section 1030 using TxDOT-PMIS Model

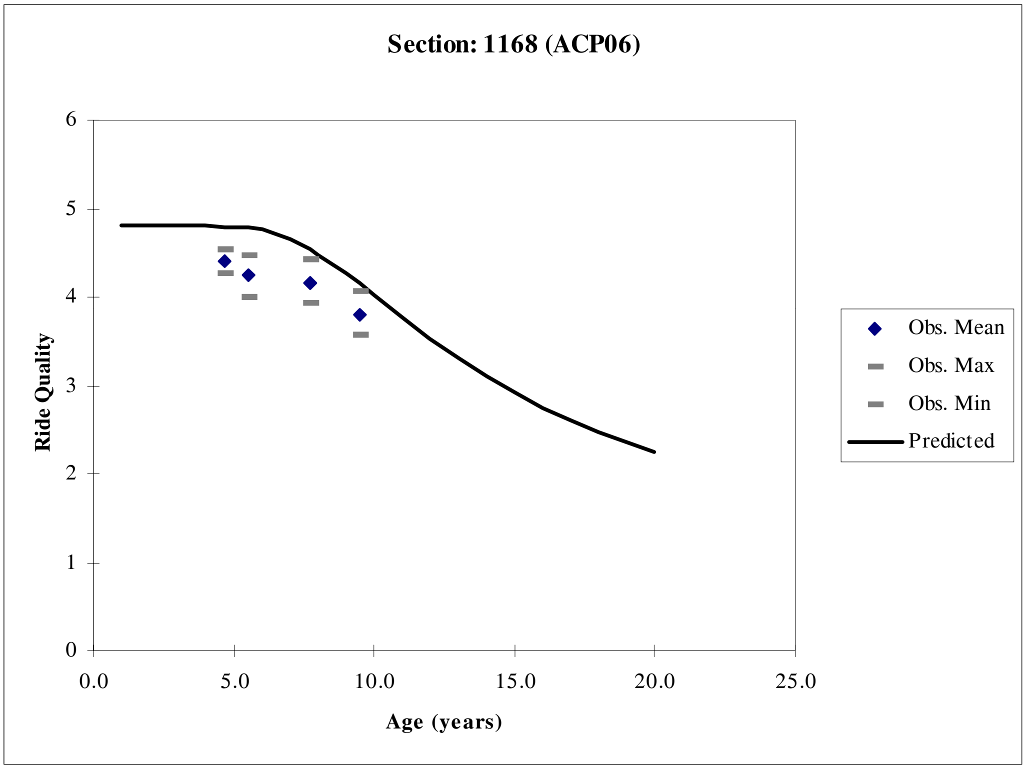


FIGURE D.10 Roughness Observed Versus Predicted for Section 1168 using TxDOT-PMIS Model

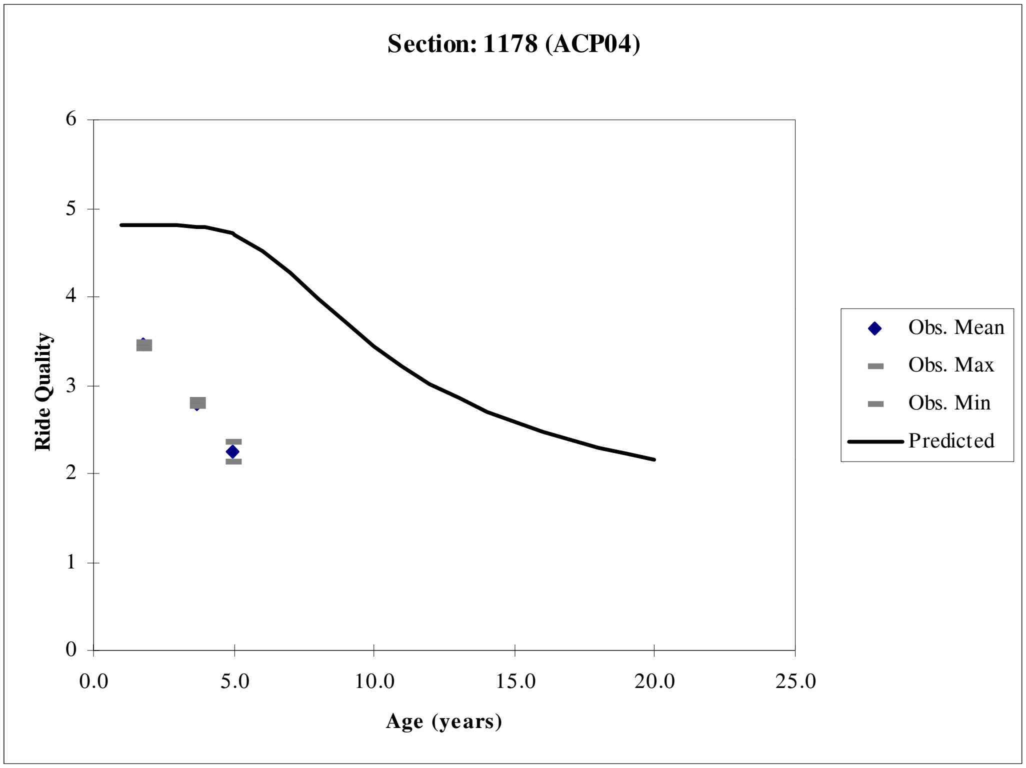


FIGURE D.11 Roughness Observed Versus Predicted for Section 1178 using TxDOT-PMIS Model

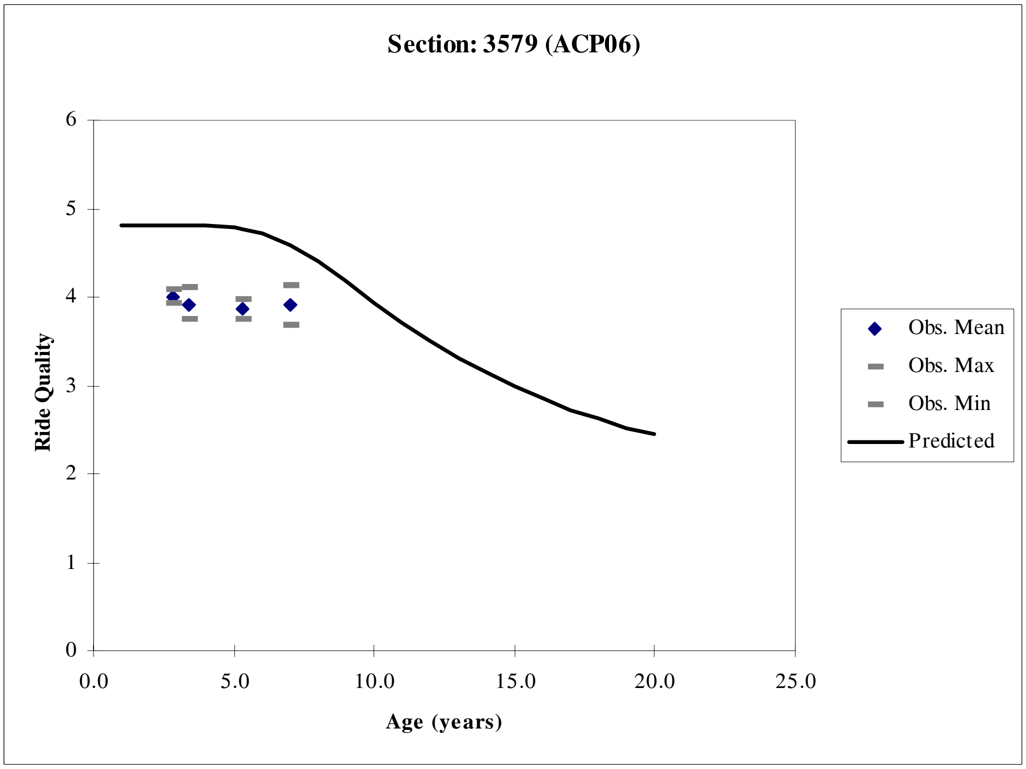


FIGURE D.12 Roughness Observed Versus Predicted for Section 3579 using TxDOT-PMIS Model

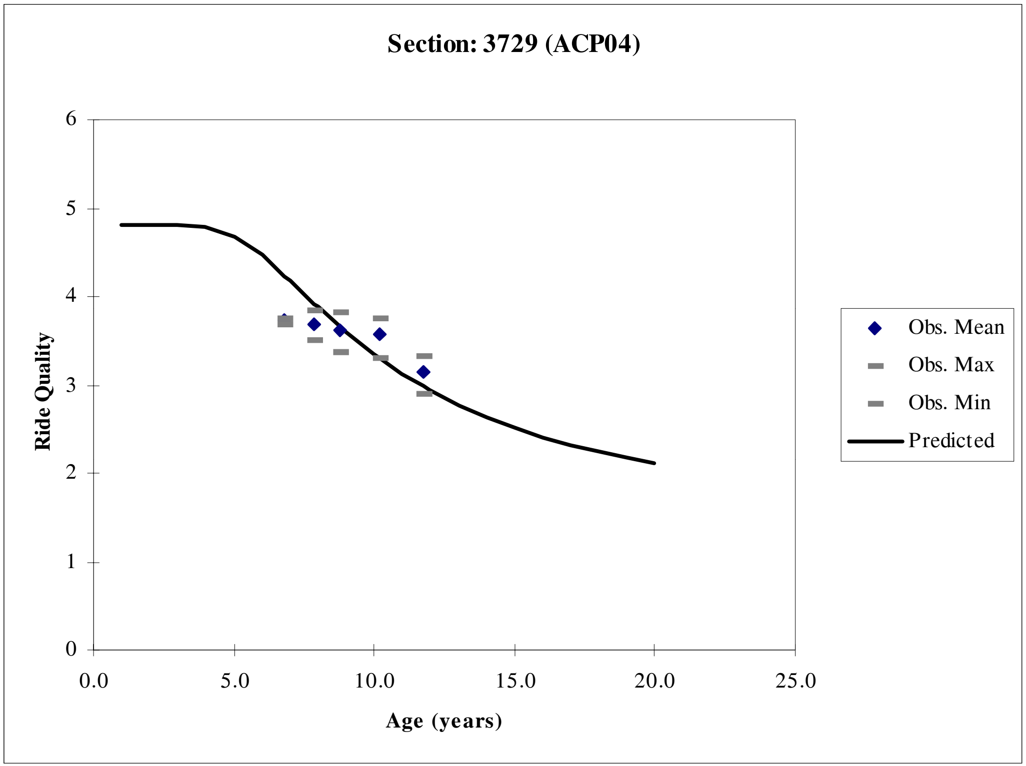


FIGURE D.13 Roughness Observed Versus Predicted for Section 3729 using TxDOT-PMIS Model

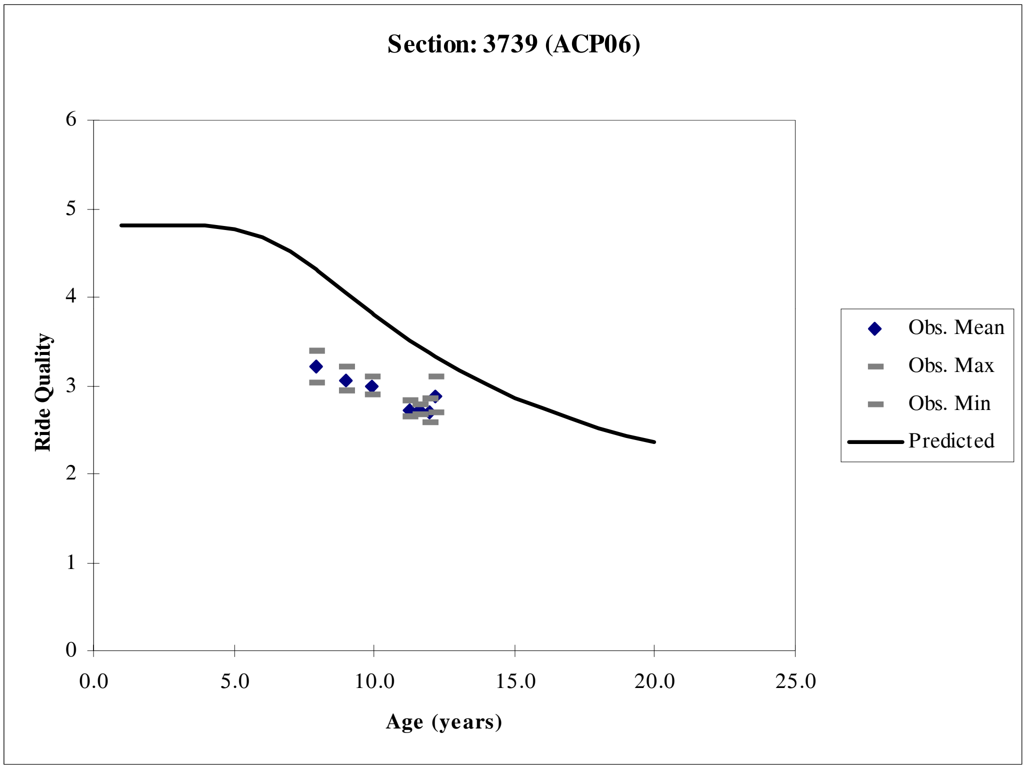


FIGURE D.14 Roughness Observed Versus Predicted for Section 3739 using TxDOT-PMIS Model

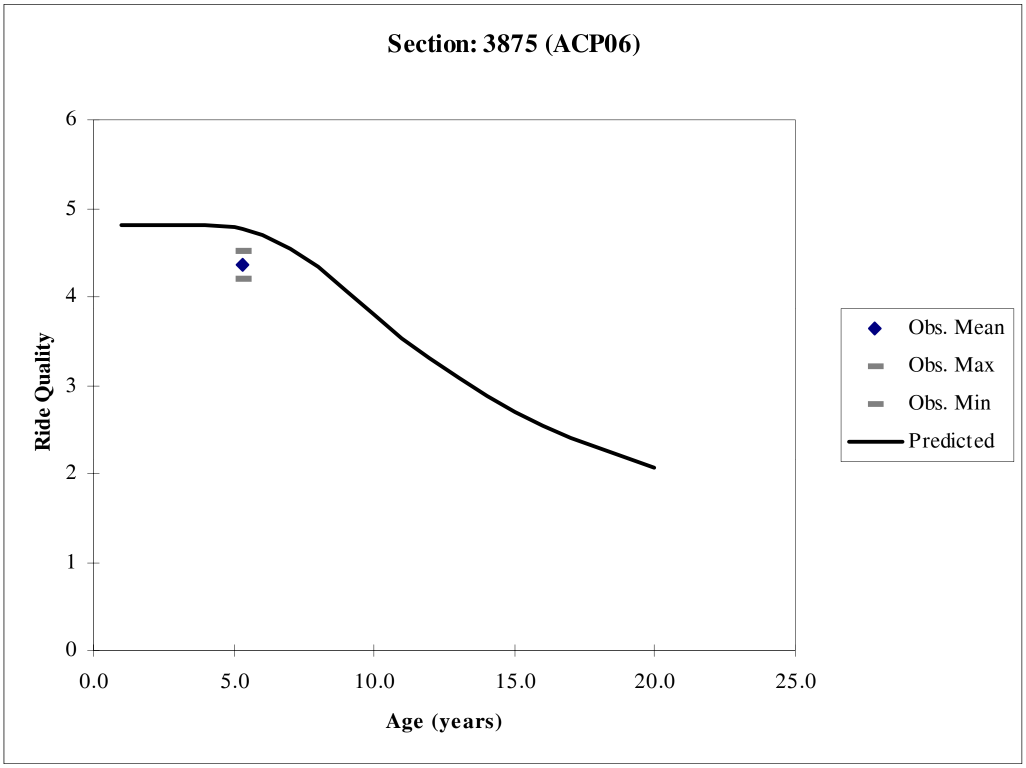


FIGURE D.15 Roughness Observed Versus Predicted for Section 3875 using TxDOT-PMIS Model

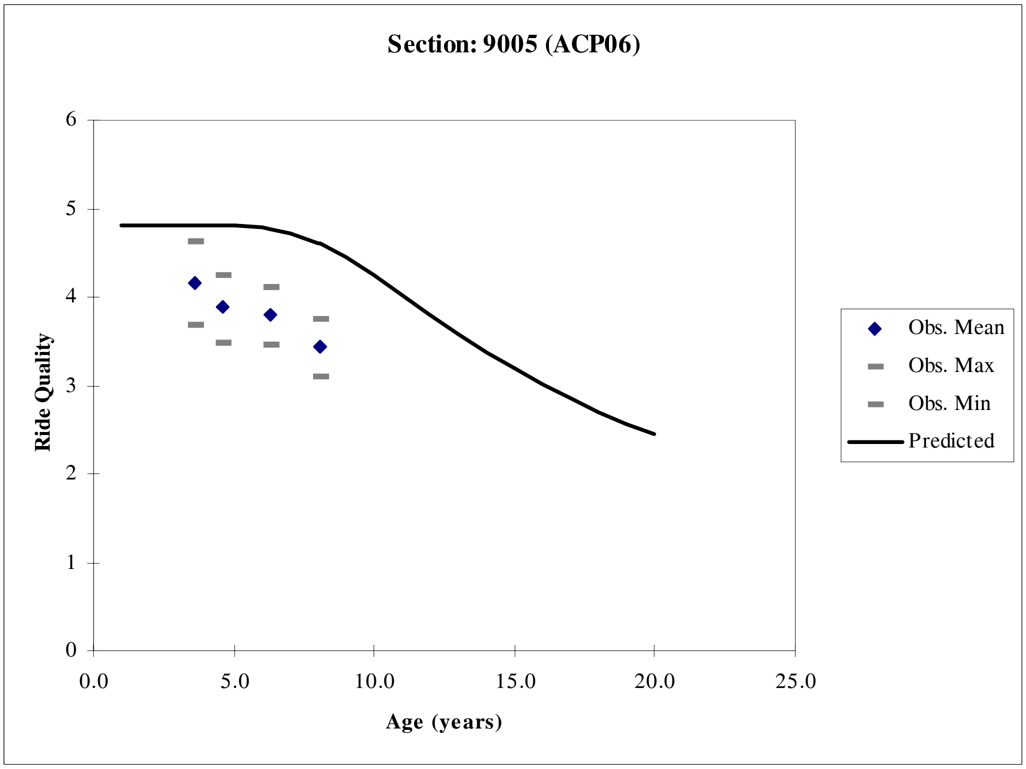


FIGURE D.16 Roughness Observed Versus Predicted for Section 9005 using TxDOT-PMIS Model

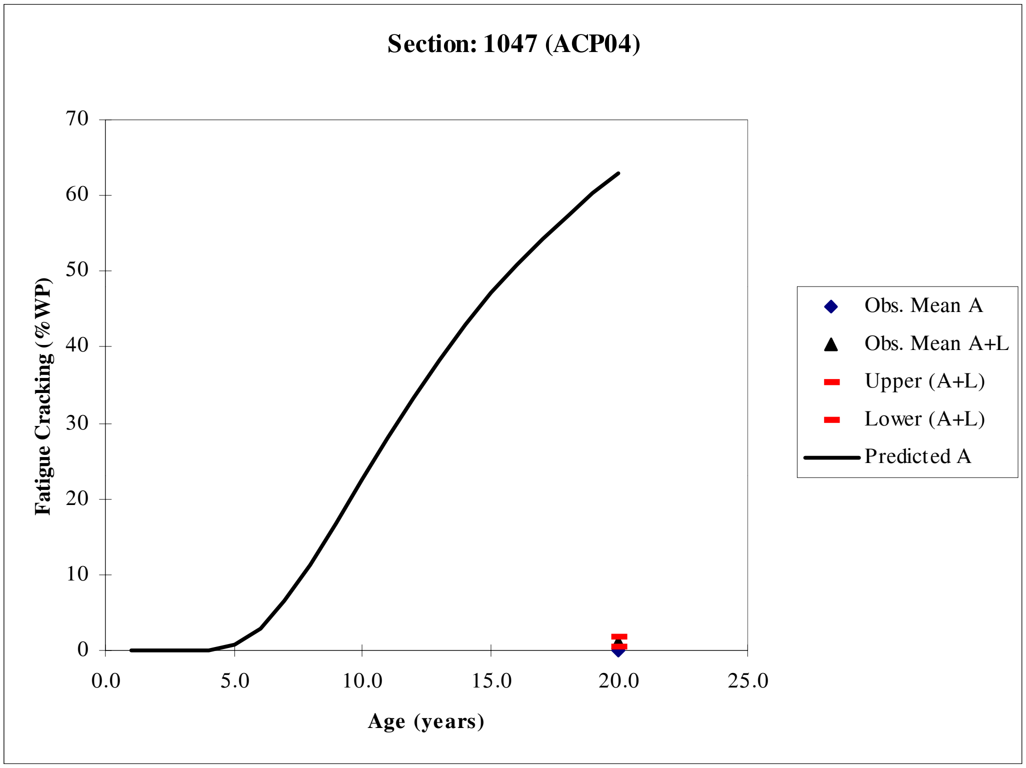


FIGURE D.17 Alligator Cracking Observed Versus Predicted for Section 1047 using PMIS Model

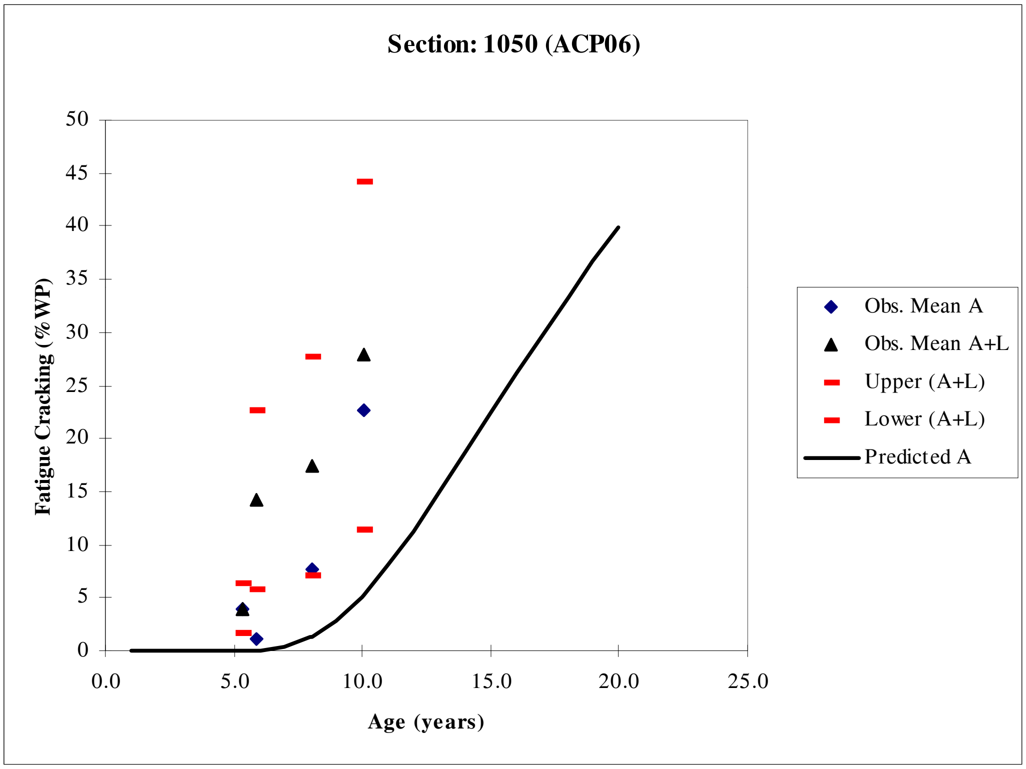


FIGURE D.18 Alligator Cracking Observed Versus Predicted for Section 1050 using PMIS Model

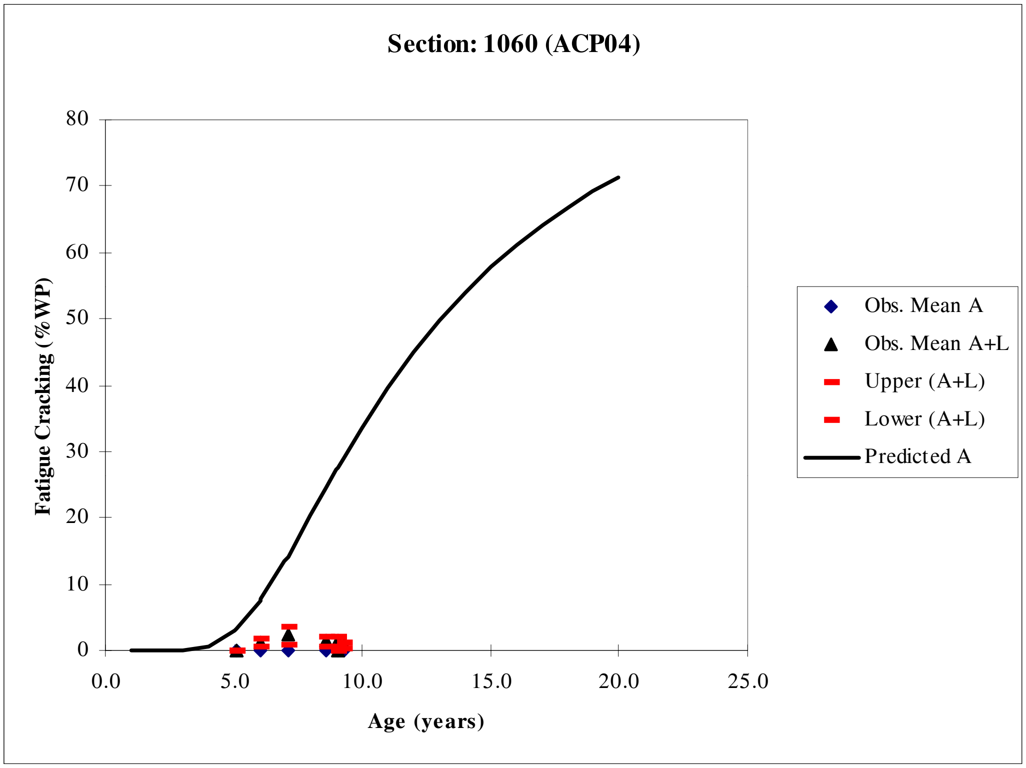


FIGURE D.19 Alligator Cracking Observed Versus Predicted for Section 1060 using PMIS Model

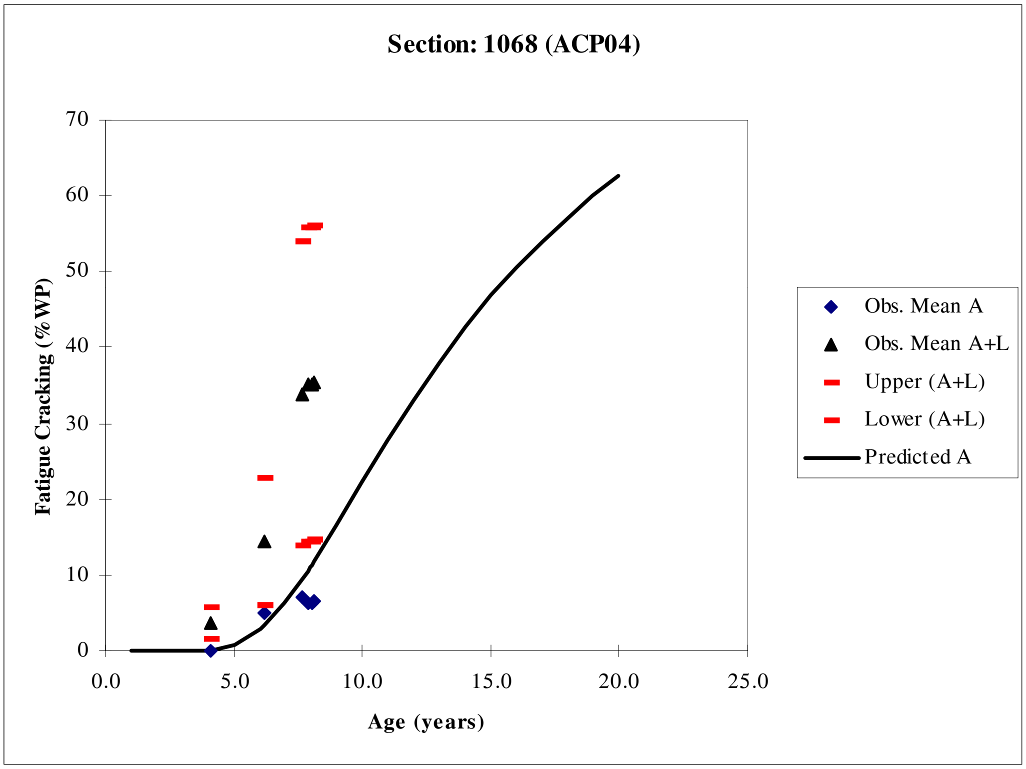


FIGURE D.20 Alligator Cracking Observed Versus Predicted for Section 1068 using PMIS Model

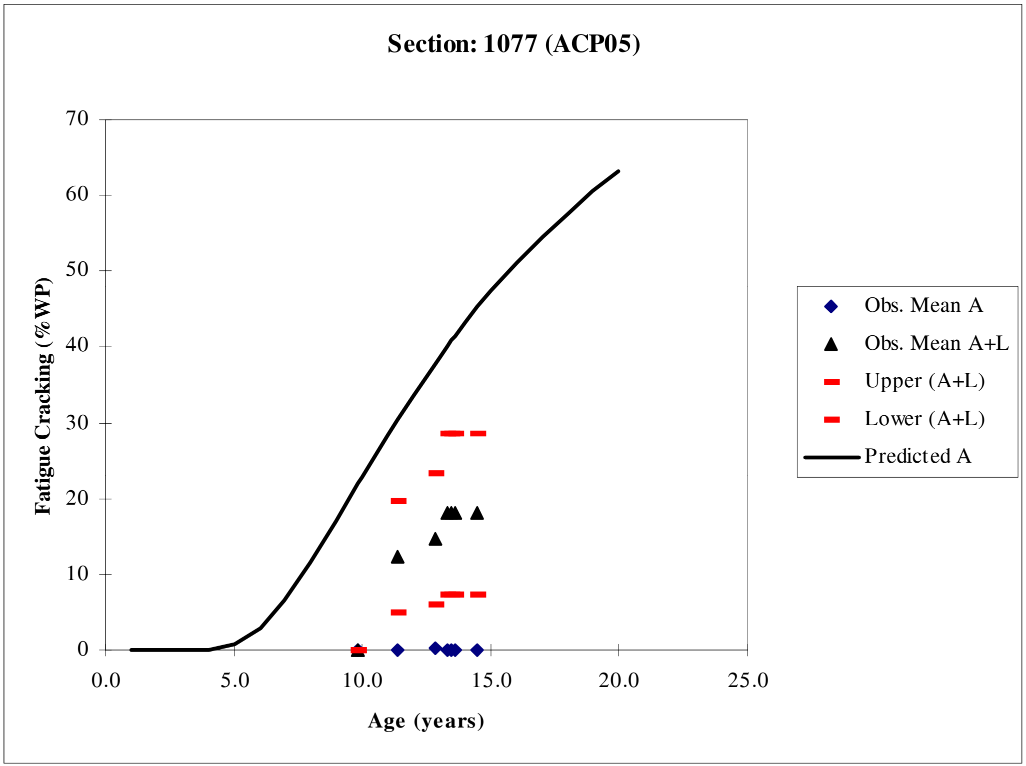


FIGURE D.21 Alligator Cracking Observed Versus Predicted for Section 1077 using PMIS Model

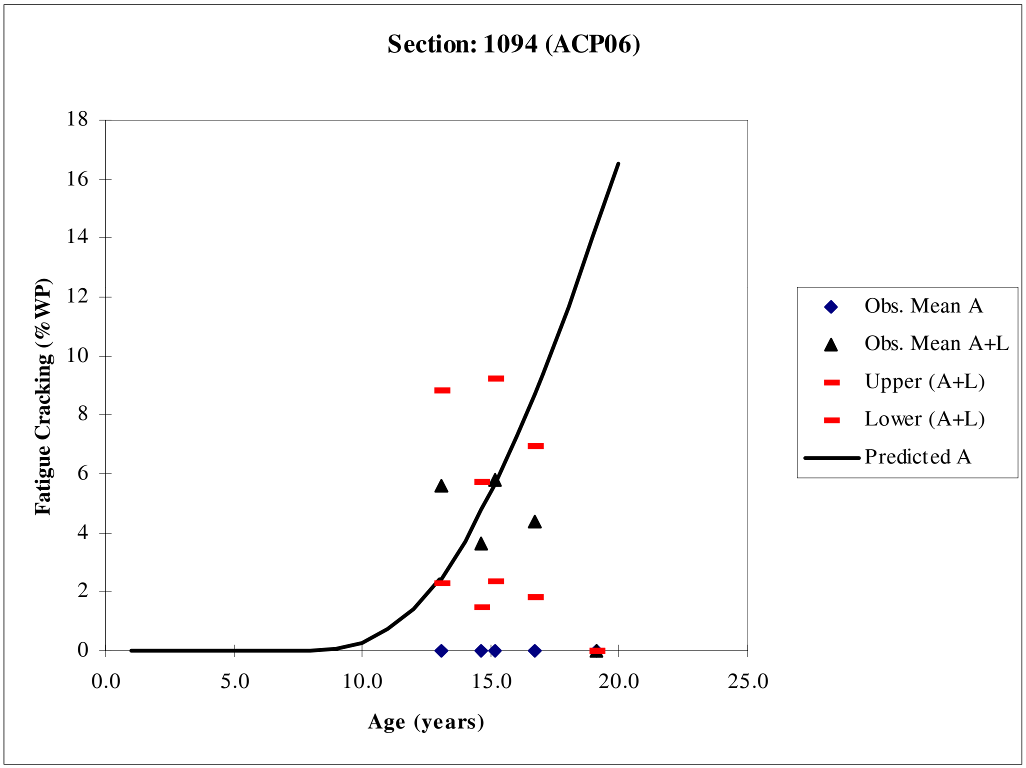


FIGURE D.22 Alligator Cracking Observed Versus Predicted for Section 1094 using PMIS Model

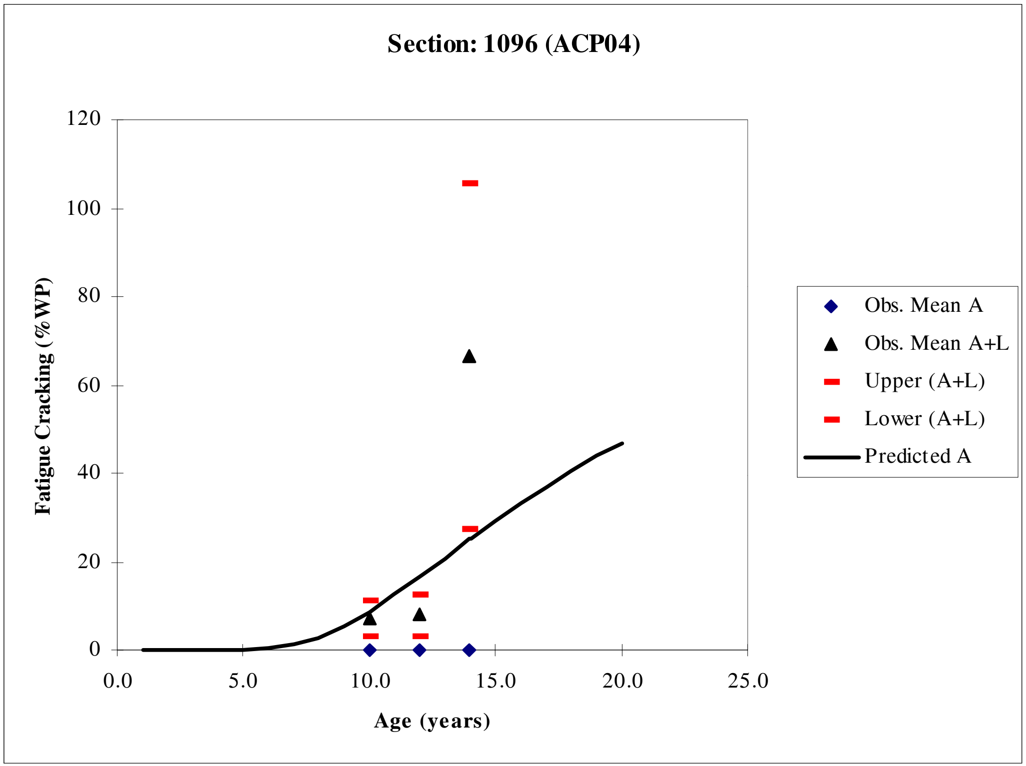


FIGURE D.23 Alligator Cracking Observed Versus Predicted for Section 1096 using PMIS Model

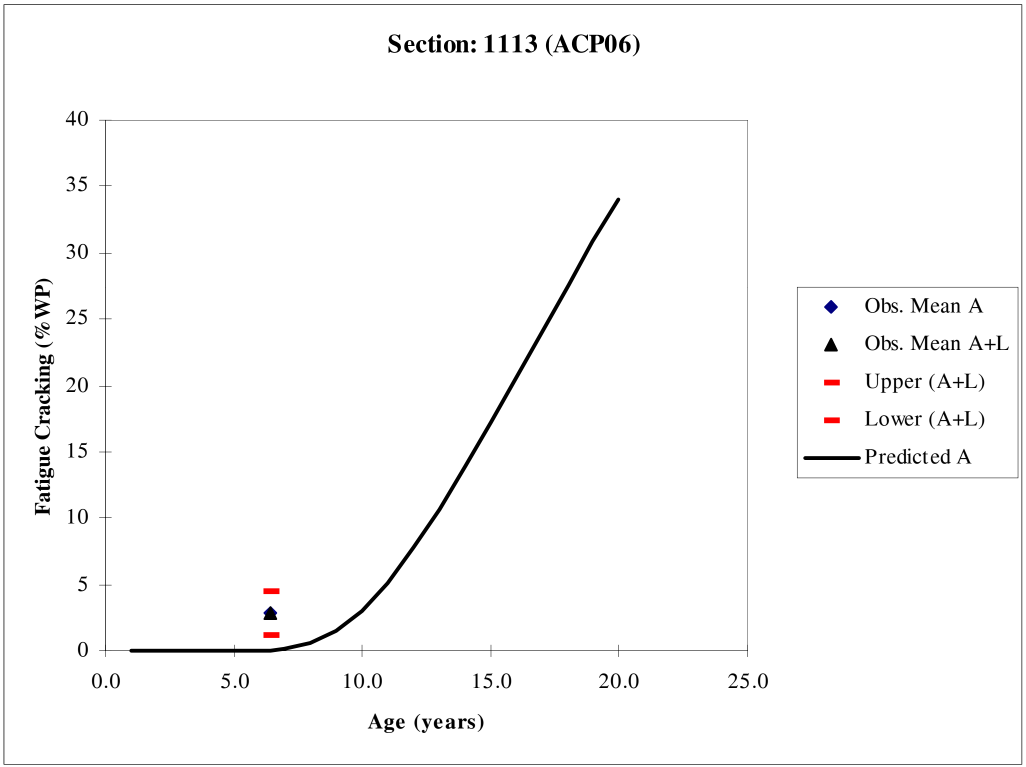


FIGURE D.24 Alligator Cracking Observed Versus Predicted for Section 1113 using PMIS Model

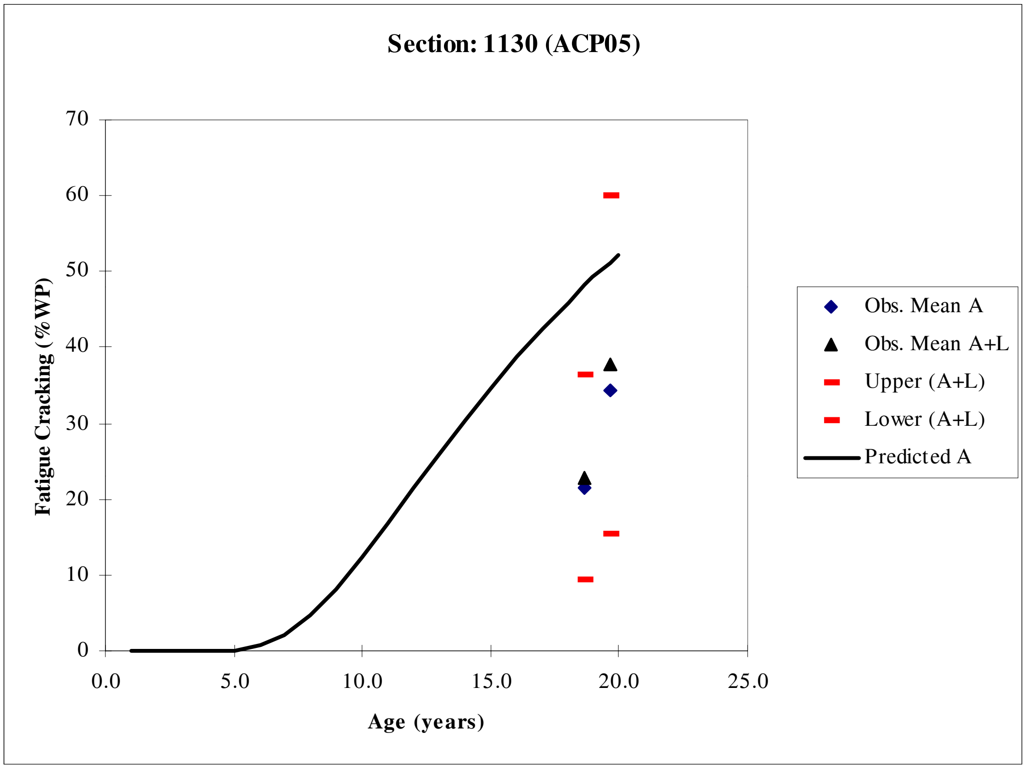


FIGURE D.25 Alligator Cracking Observed Versus Predicted for Section 1130 using PMIS Model

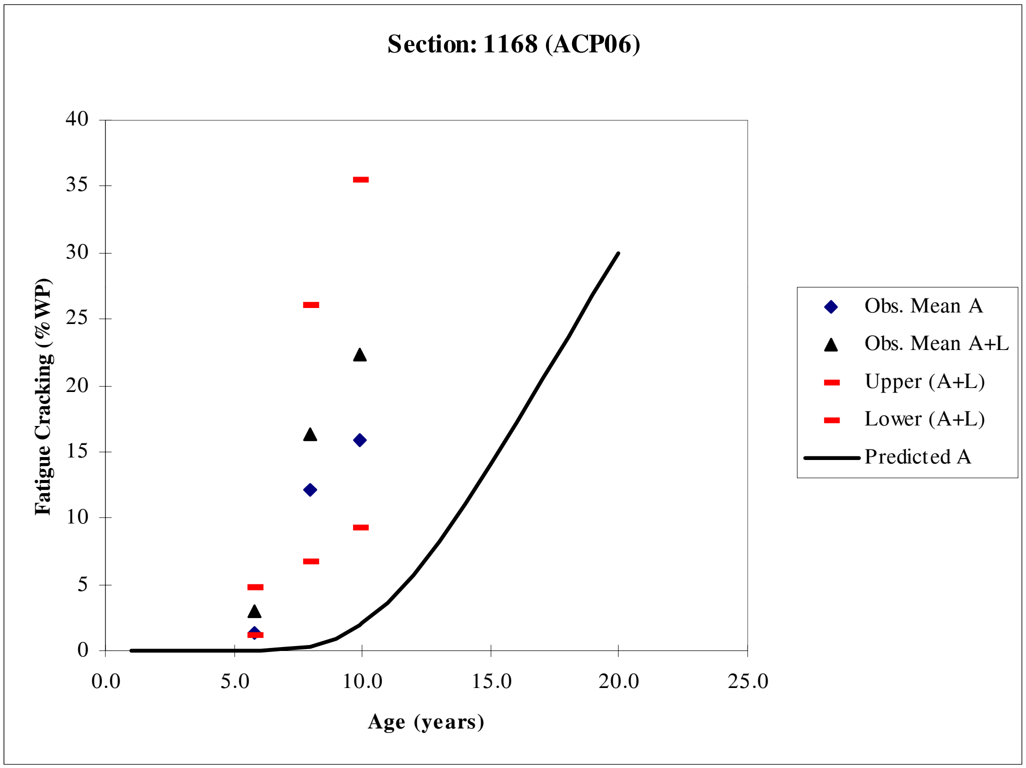


FIGURE D.26 Alligator Cracking Observed Versus Predicted for Section 1168 using PMIS Model

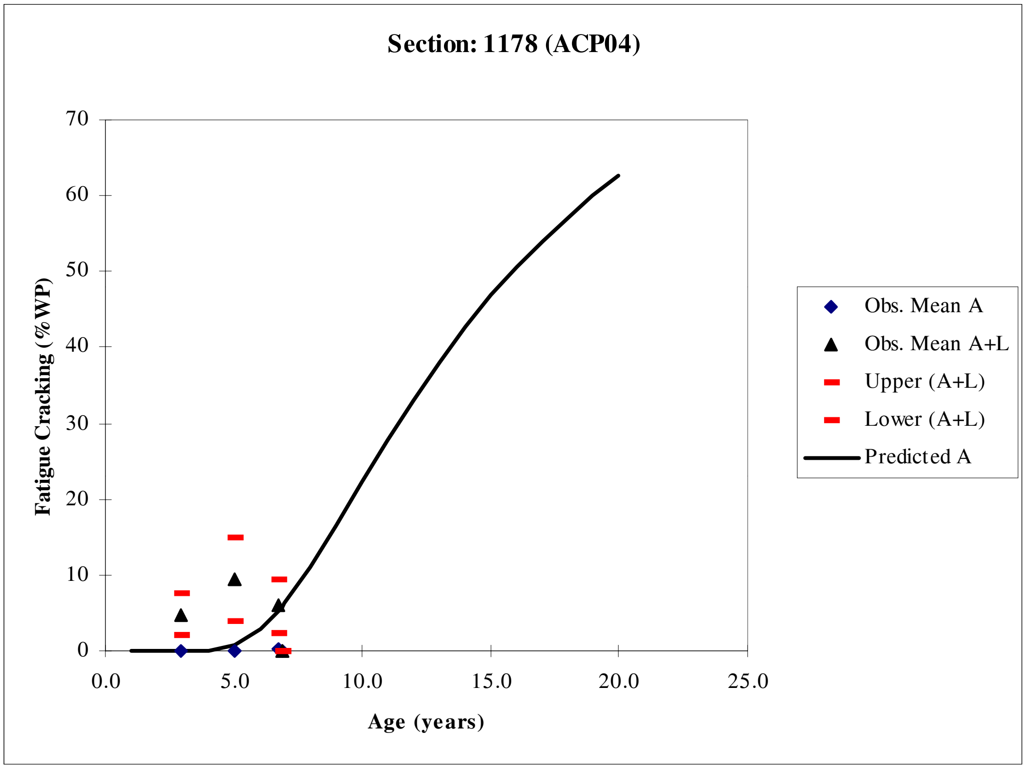


FIGURE D.27 Alligator Cracking Observed Versus Predicted for Section 1178 using PMIS Model

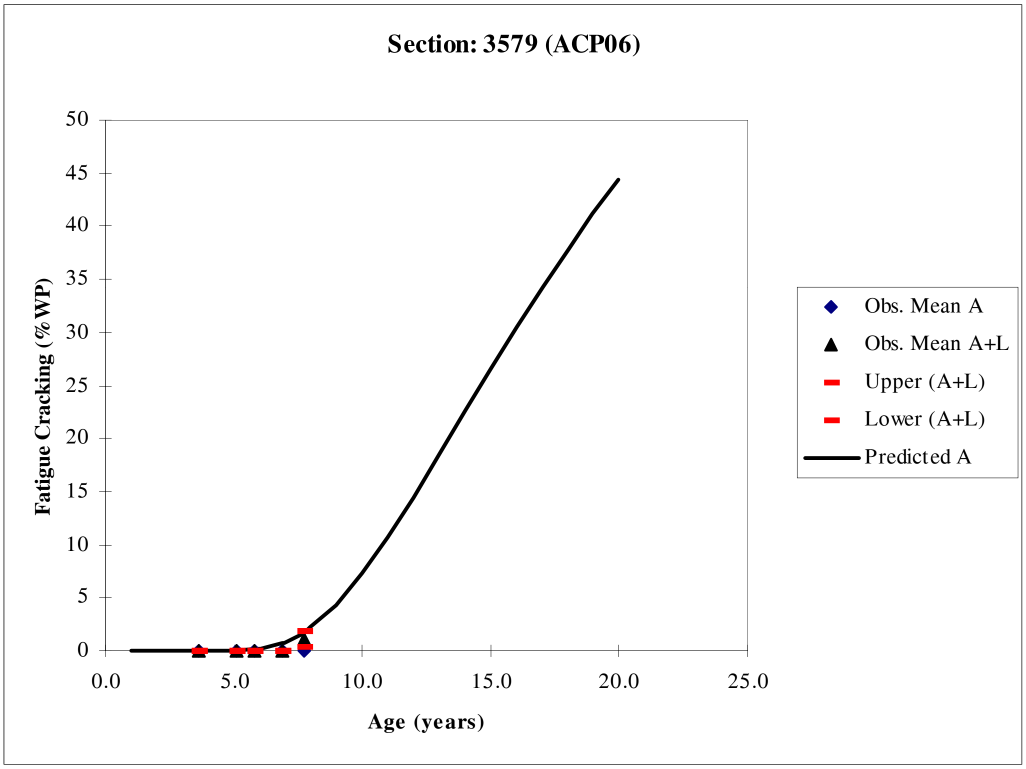


FIGURE D.28 Alligator Cracking Observed Versus Predicted for Section 3579 using PMIS Model

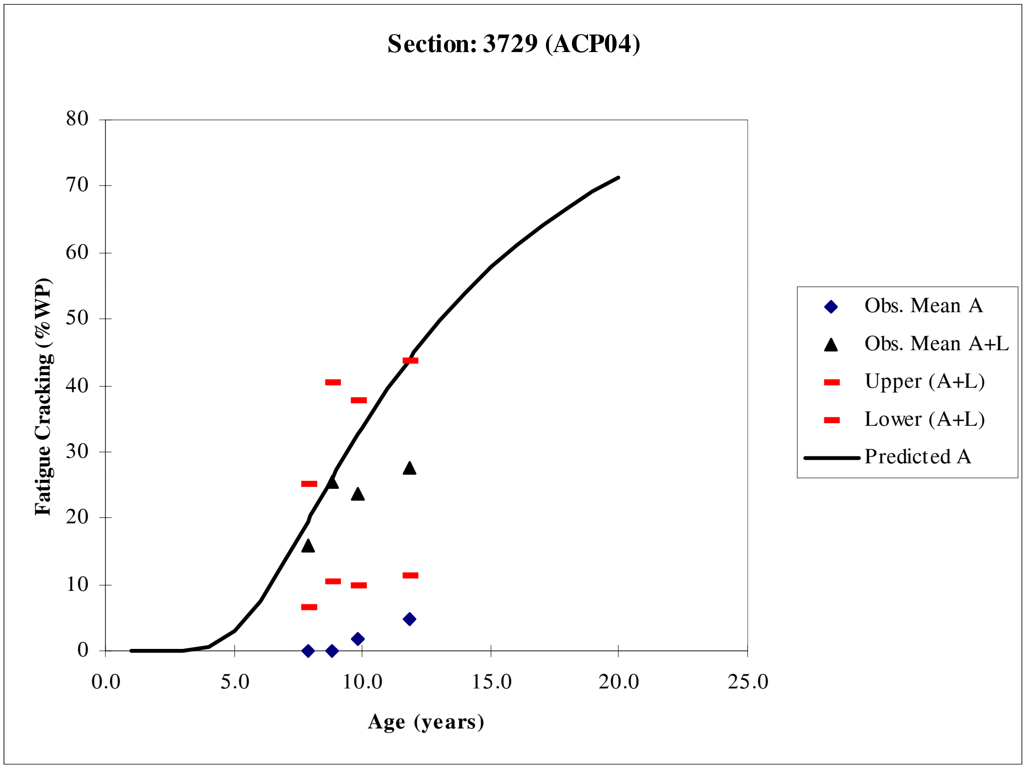


FIGURE D.29 Alligator Cracking Observed Versus Predicted for Section 3729 using PMIS Model

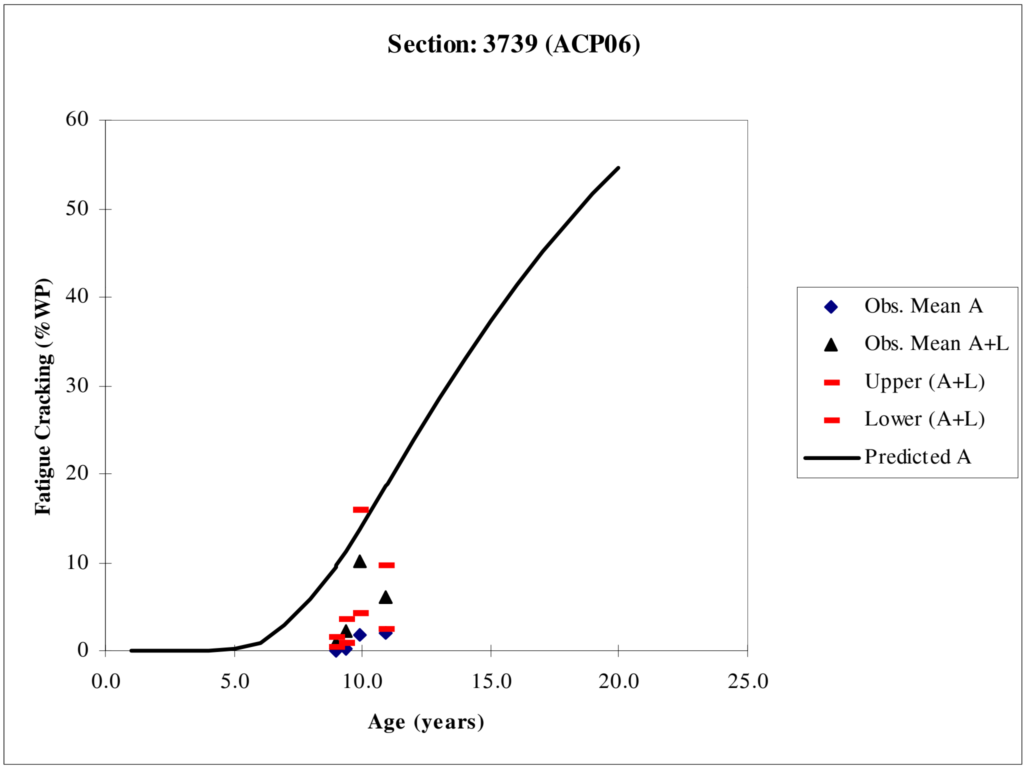


FIGURE D.30 Alligator Cracking Observed Versus Predicted for Section 3739 using PMIS Model

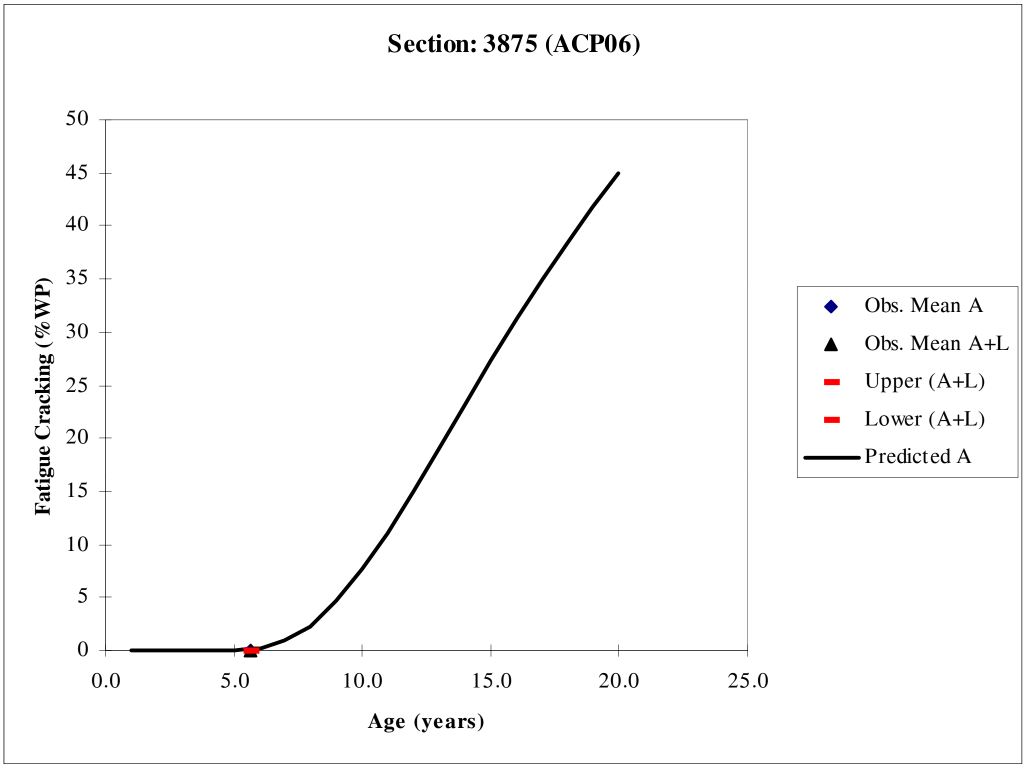


FIGURE D.31 Alligator Cracking Observed Versus Predicted for Section 3875 using PMIS Model

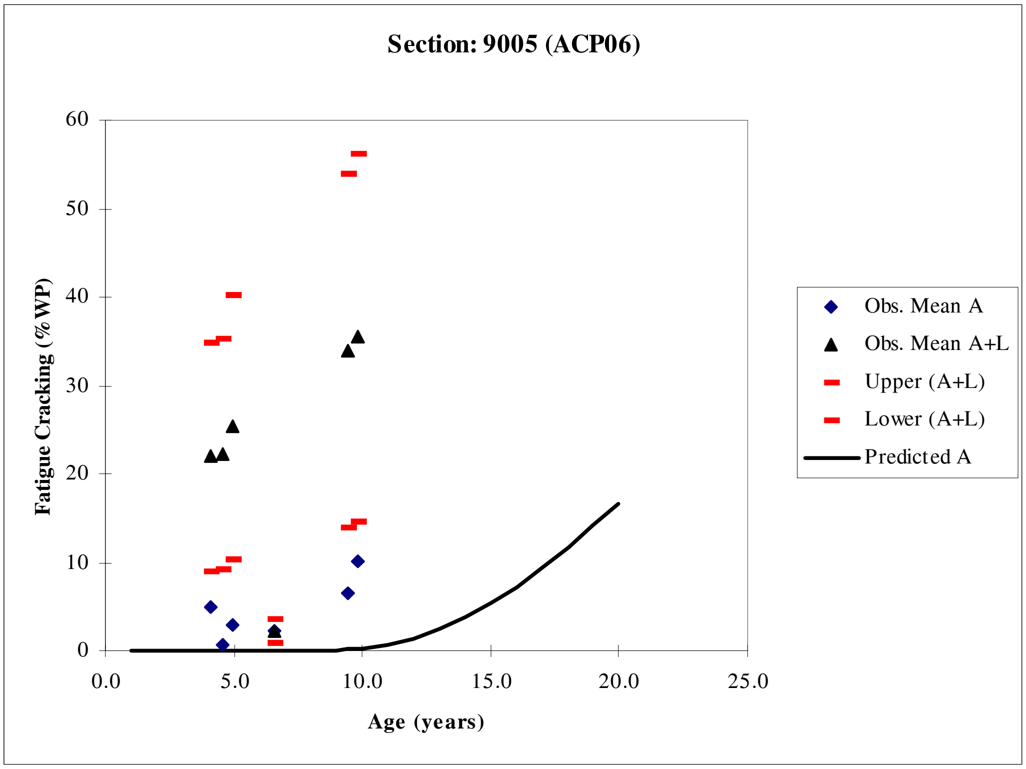


FIGURE D.32 Alligator Cracking Observed Versus Predicted for Section 9005 using PMIS Model

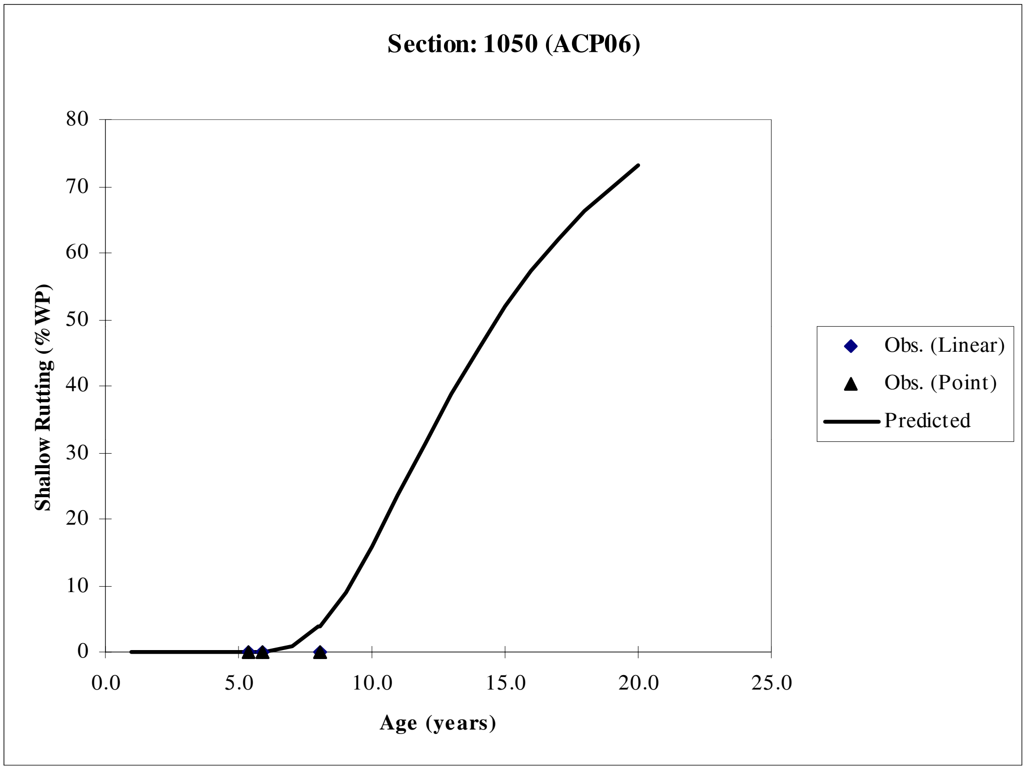


FIGURE D.33 Shallow Rutting Observed Versus Predicted for Section 1050 using PMIS Model

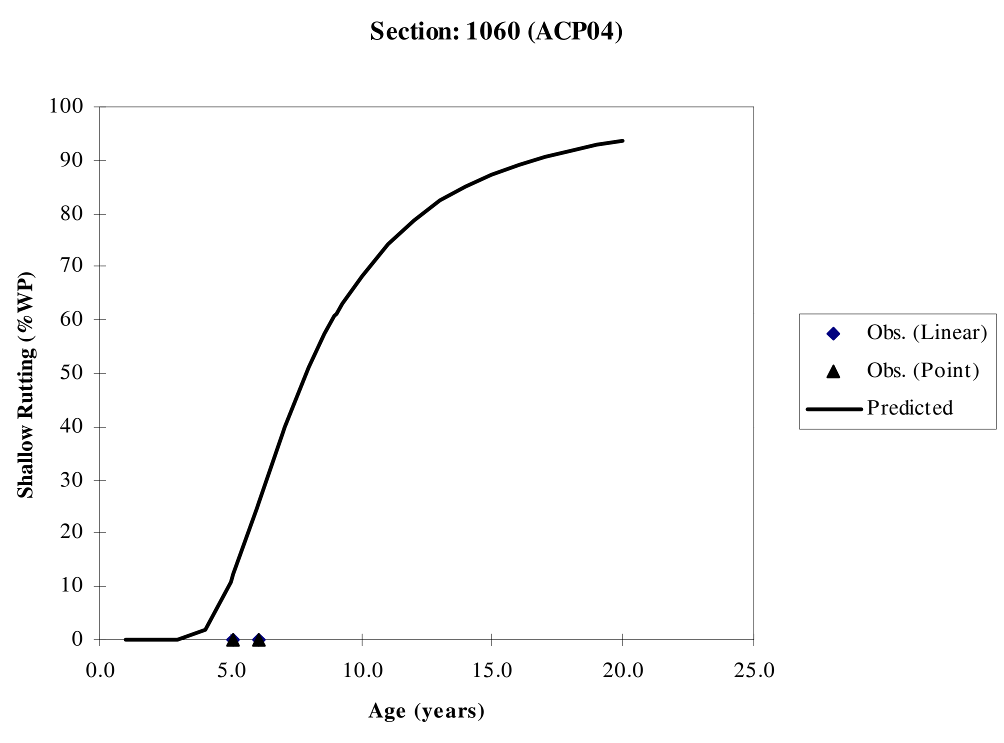


FIGURE D.34 Shallow Rutting Observed Versus Predicted for Section 1060 using PMIS Model

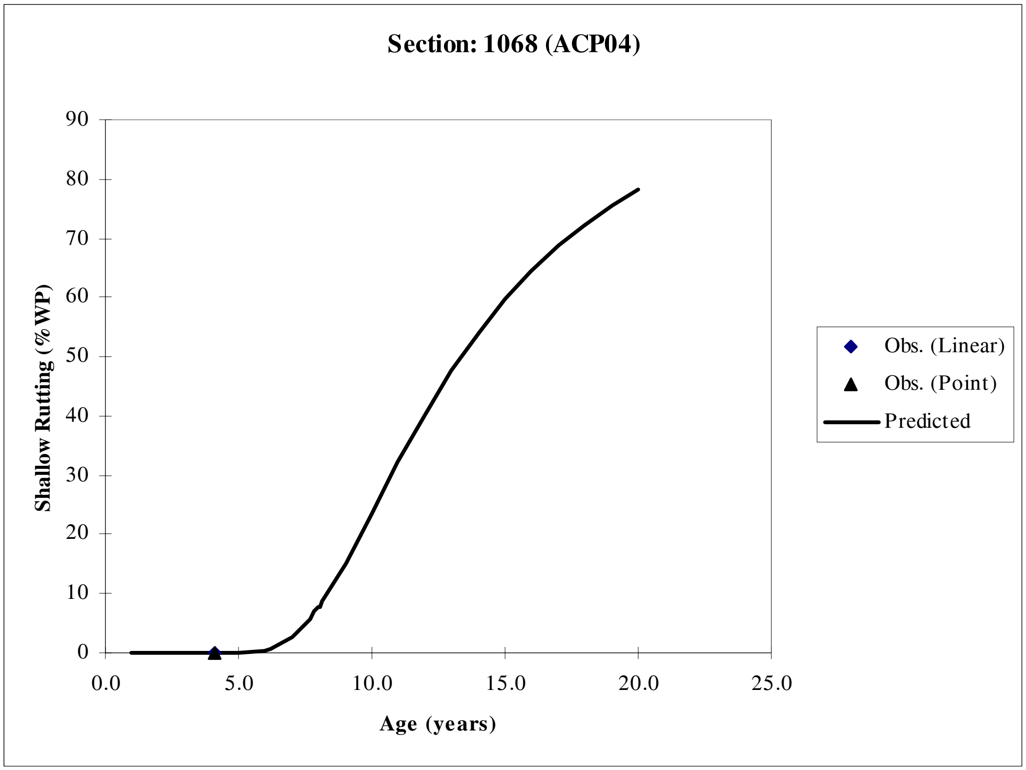


FIGURE D.35 Shallow Rutting Observed Versus Predicted for Section 1068 using PMIS Model

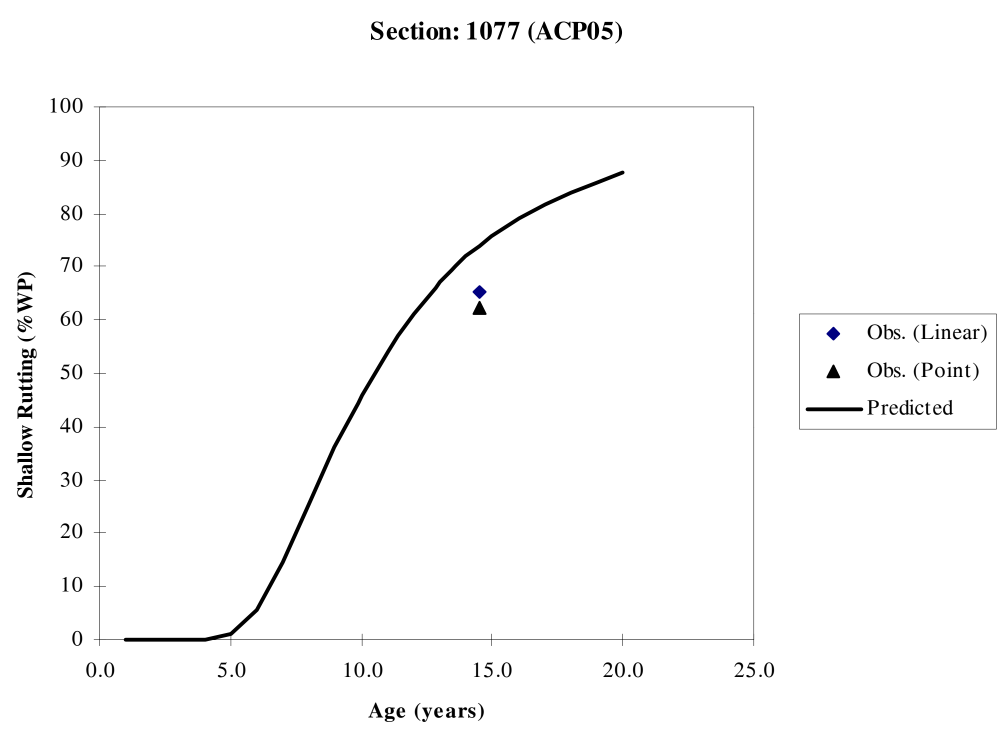


FIGURE D.36 Shallow Rutting Observed Versus Predicted for Section 1077 using PMIS Model

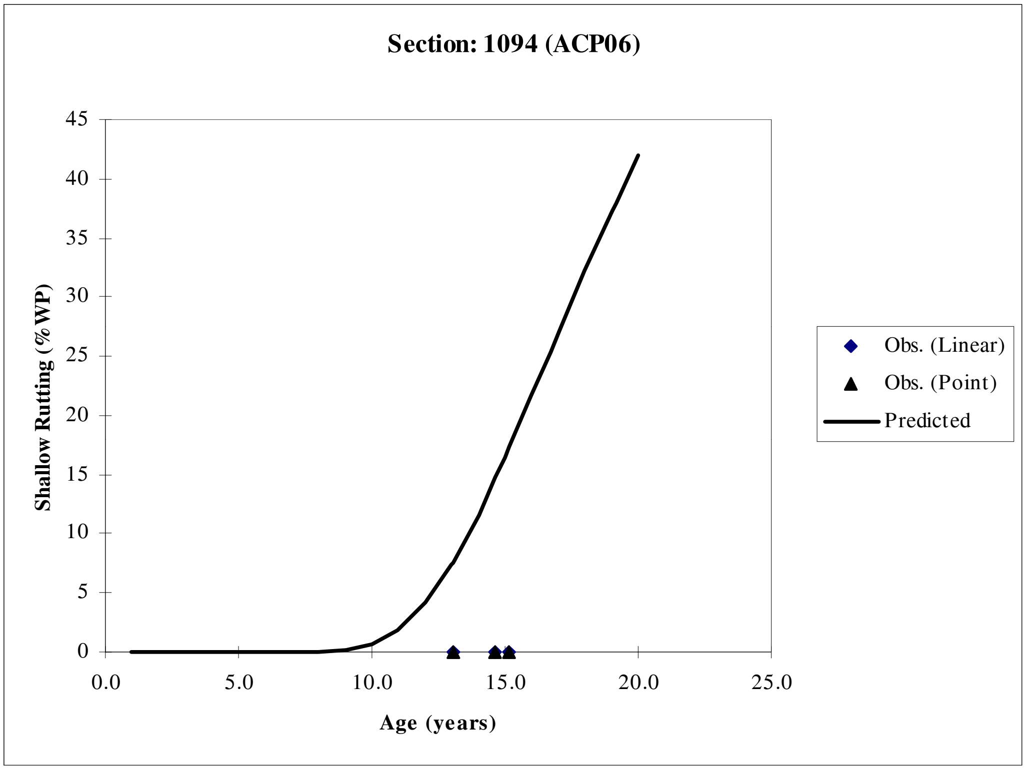


FIGURE D.37 Shallow Rutting Observed Versus Predicted for Section 1094 using PMIS Model

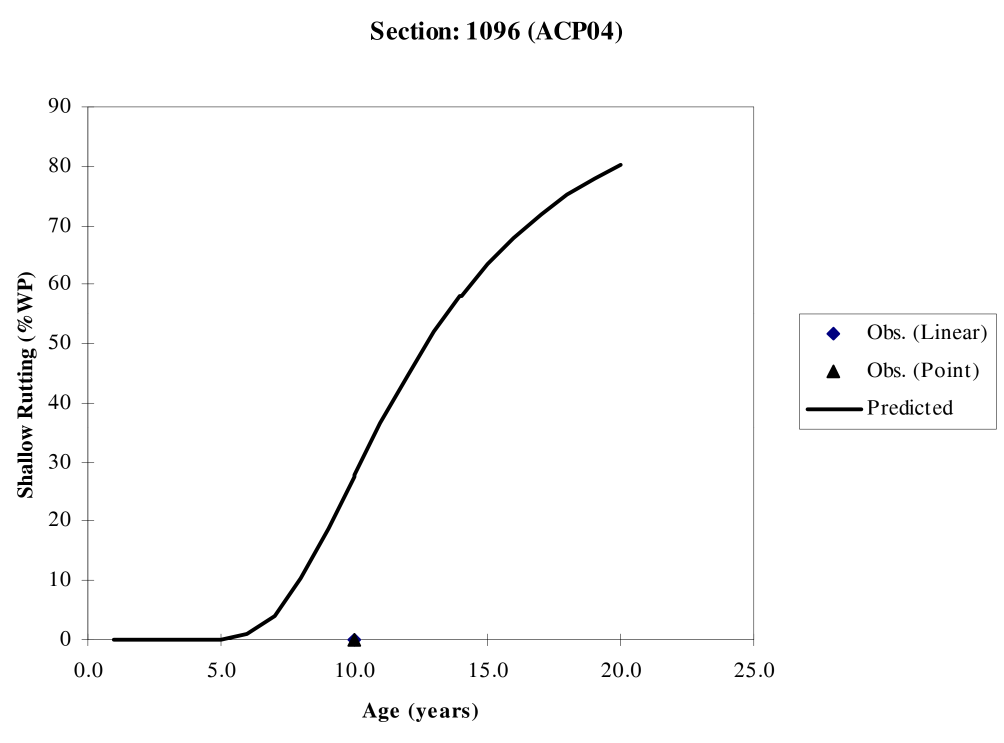


FIGURE D.38 Shallow Rutting Observed Versus Predicted for Section 1096 using PMIS Model

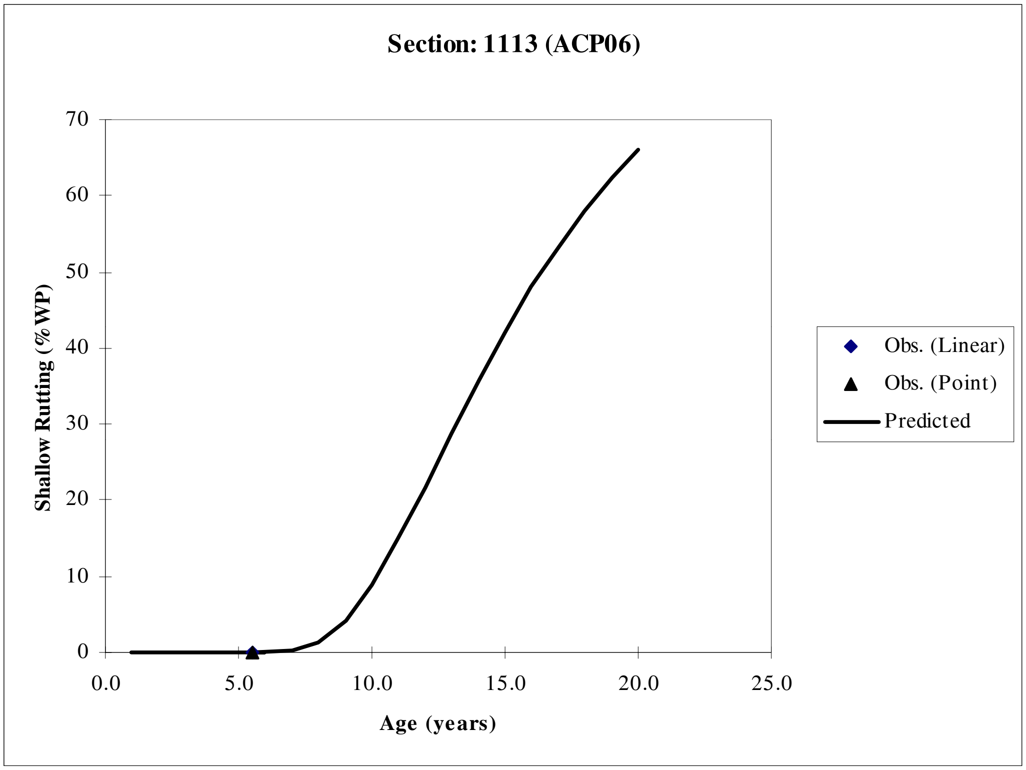


FIGURE D.39 Shallow Rutting Observed Versus Predicted for Section 1113 using PMIS Model

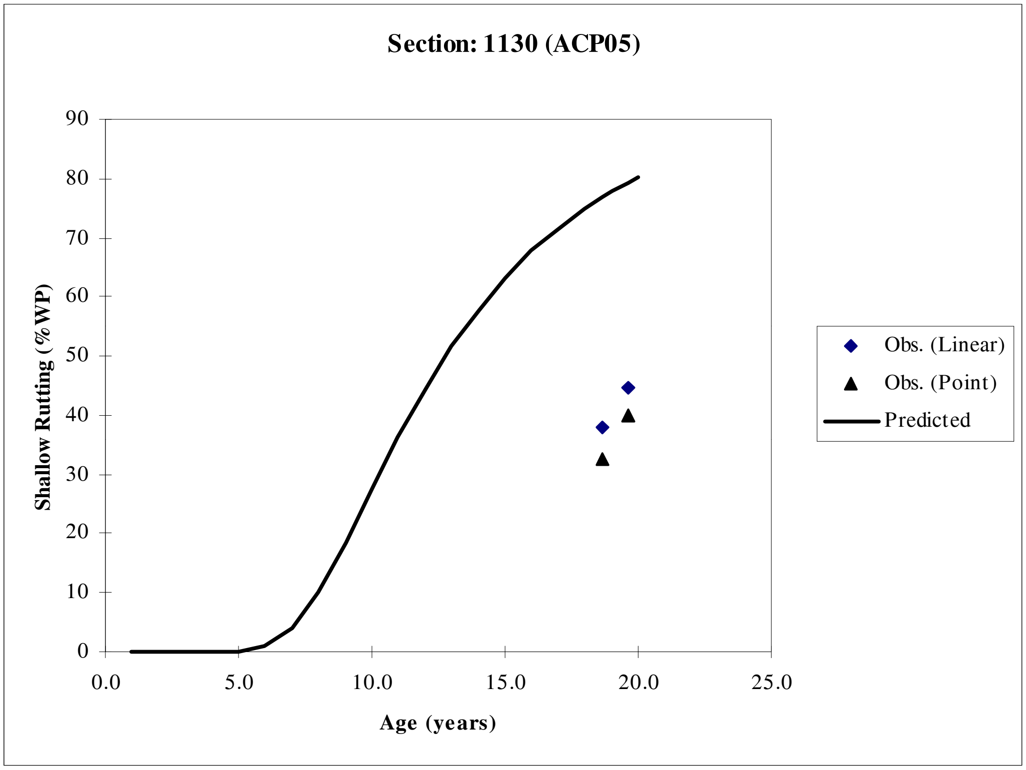


FIGURE D.40 Shallow Rutting Observed Versus Predicted for Section 1130 using PMIS Model

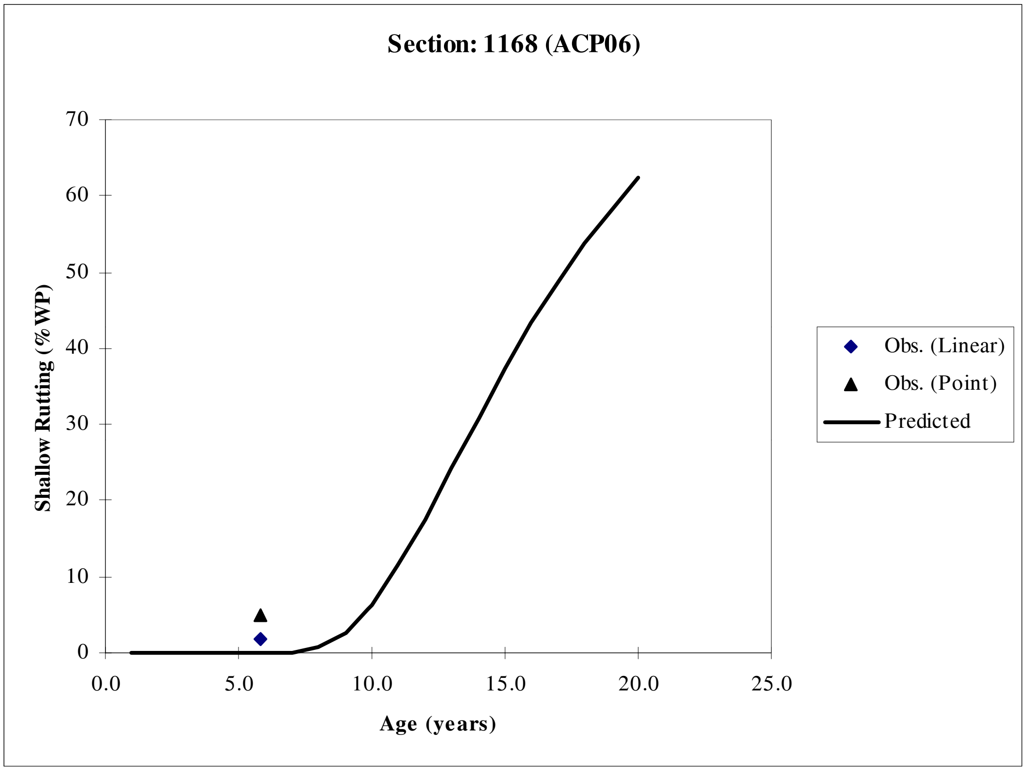


FIGURE D.41 Shallow Rutting Observed Versus Predicted for Section 1168 using PMIS Model

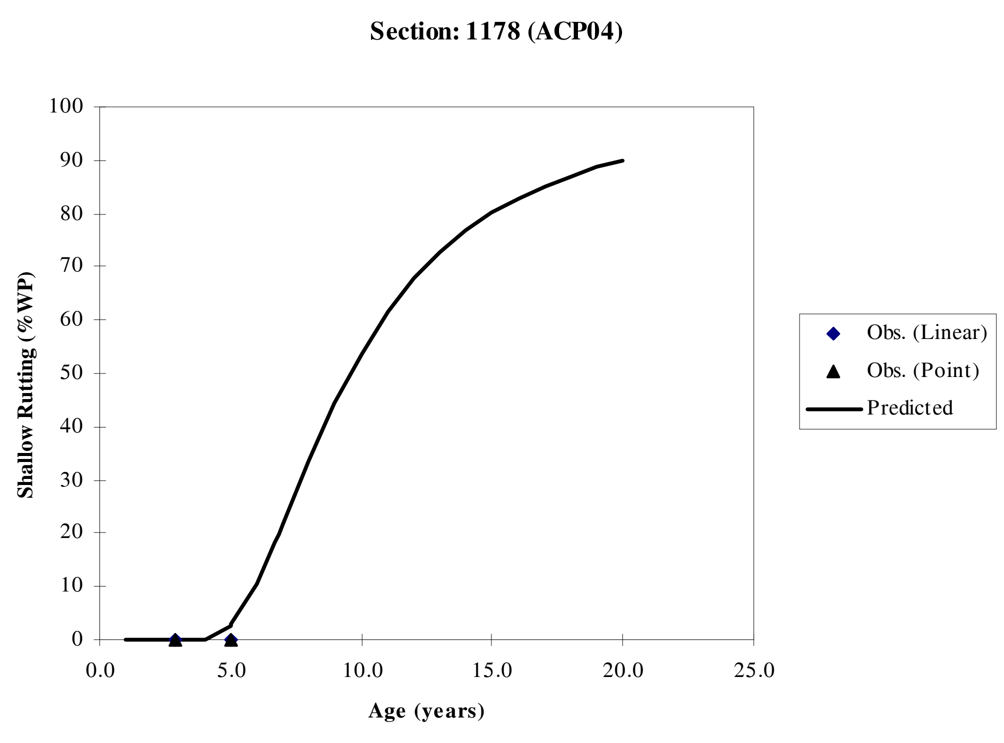


FIGURE D.42 Shallow Rutting Observed Versus Predicted for Section 1178 using PMIS Model

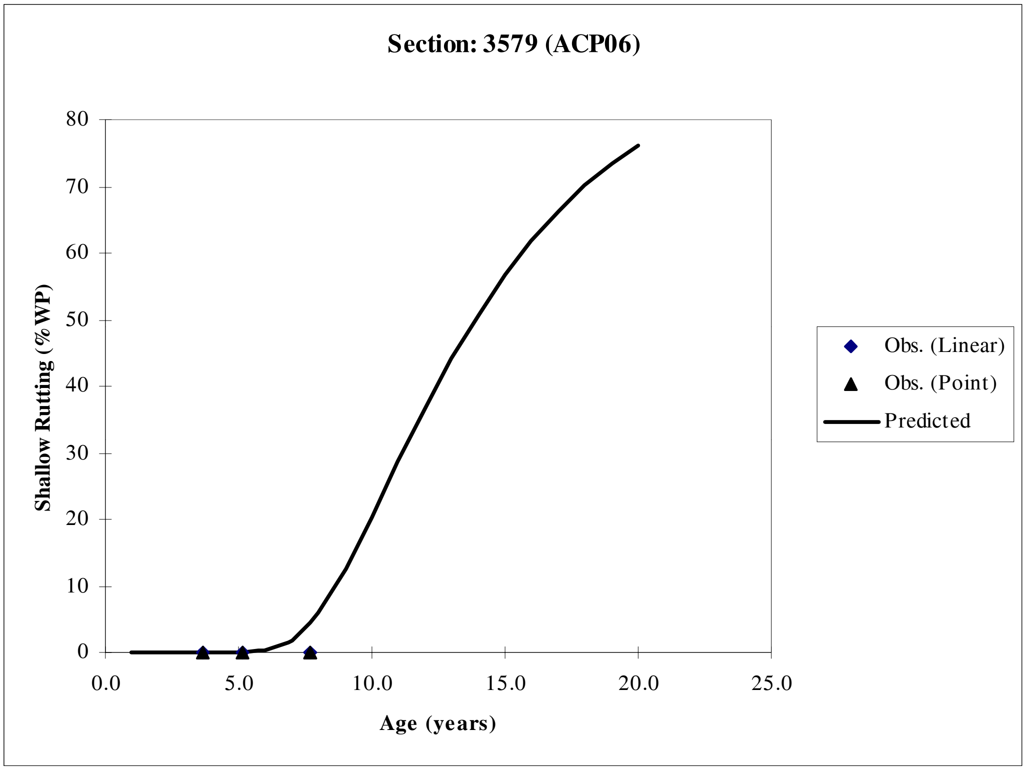


FIGURE D.43 Shallow Rutting Observed Versus Predicted for Section 3579 using PMIS Model

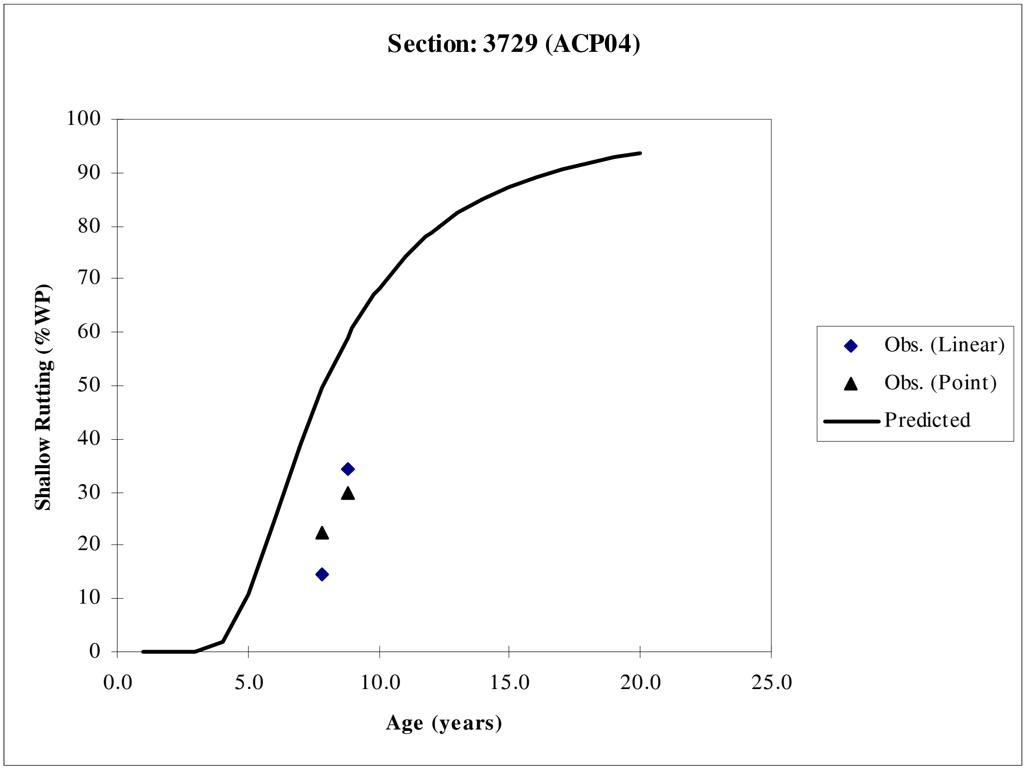


FIGURE D.44 Shallow Rutting Observed Versus Predicted for Section 3729 using PMIS Model

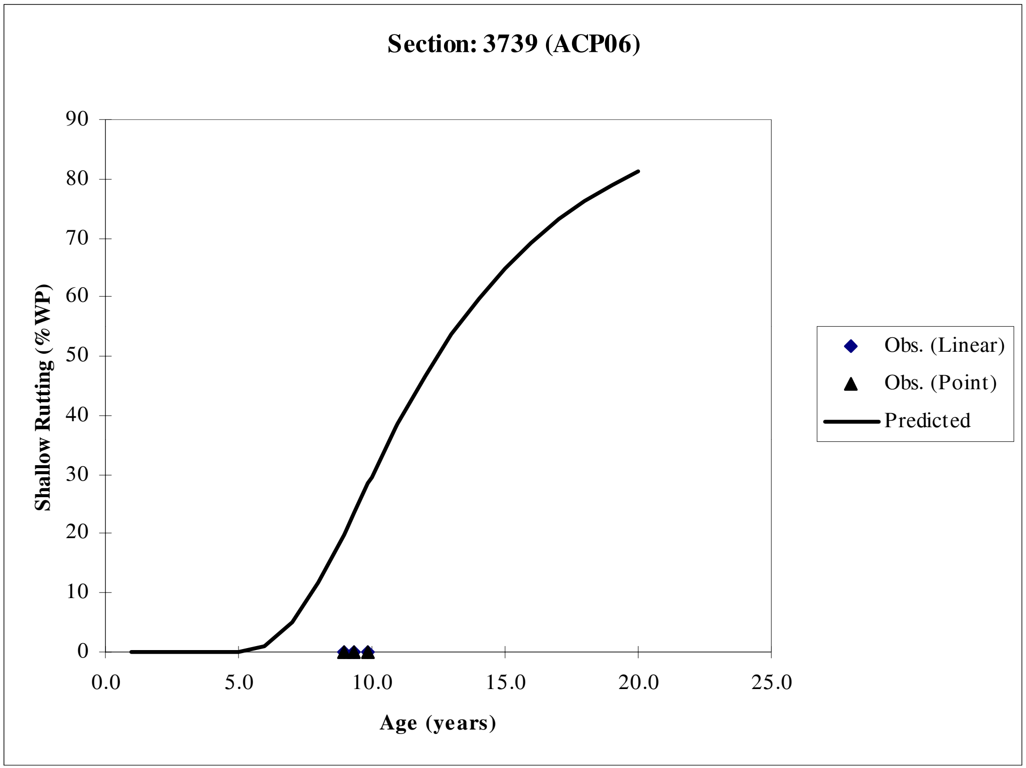


FIGURE D.45 Shallow Rutting Observed Versus Predicted for Section 3739 using PMIS Model

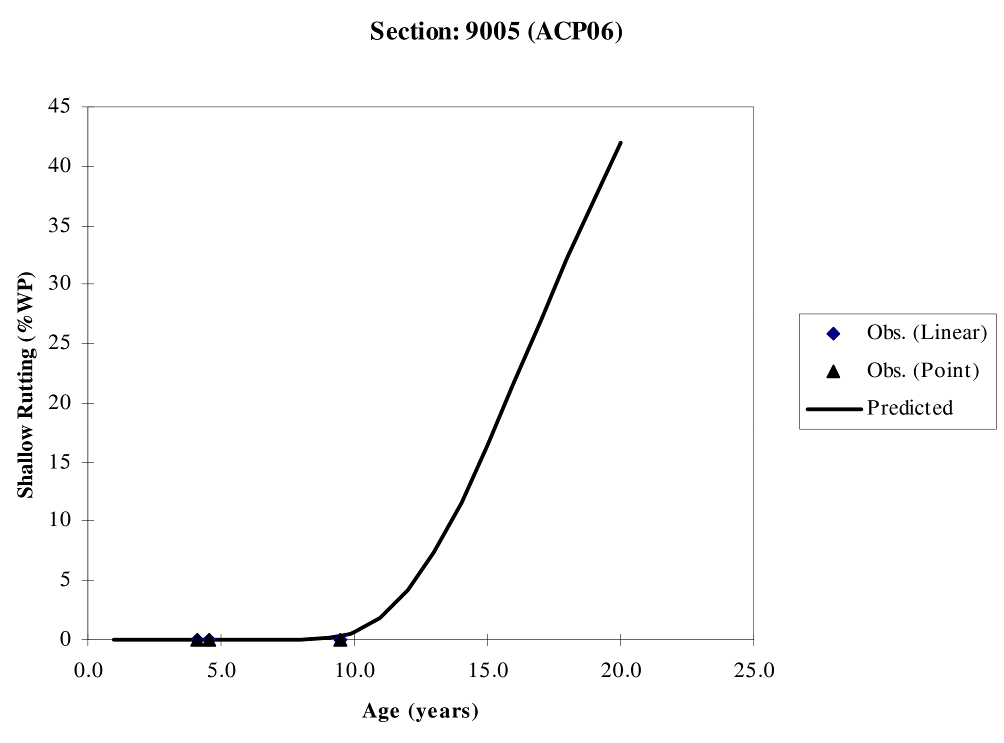


FIGURE D.46 Shallow Rutting Observed Versus Predicted for Section 9005 using PMIS Model

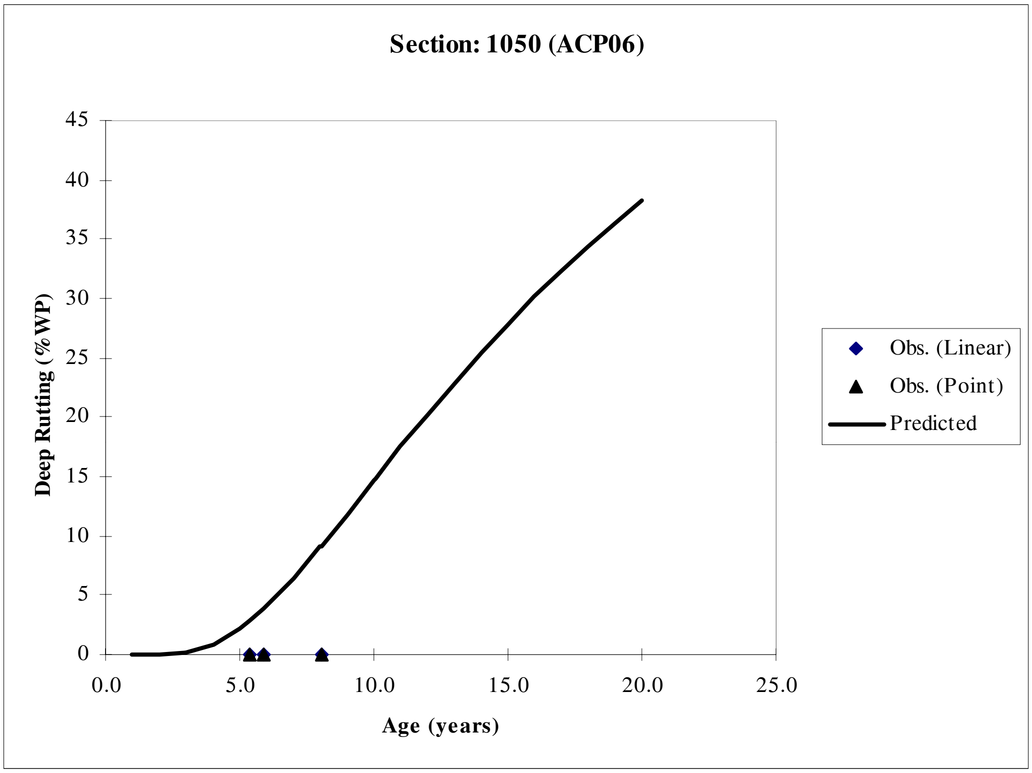


FIGURE D.47 Deep Rutting Observed Versus Predicted for Section 1050 using PMIS Model

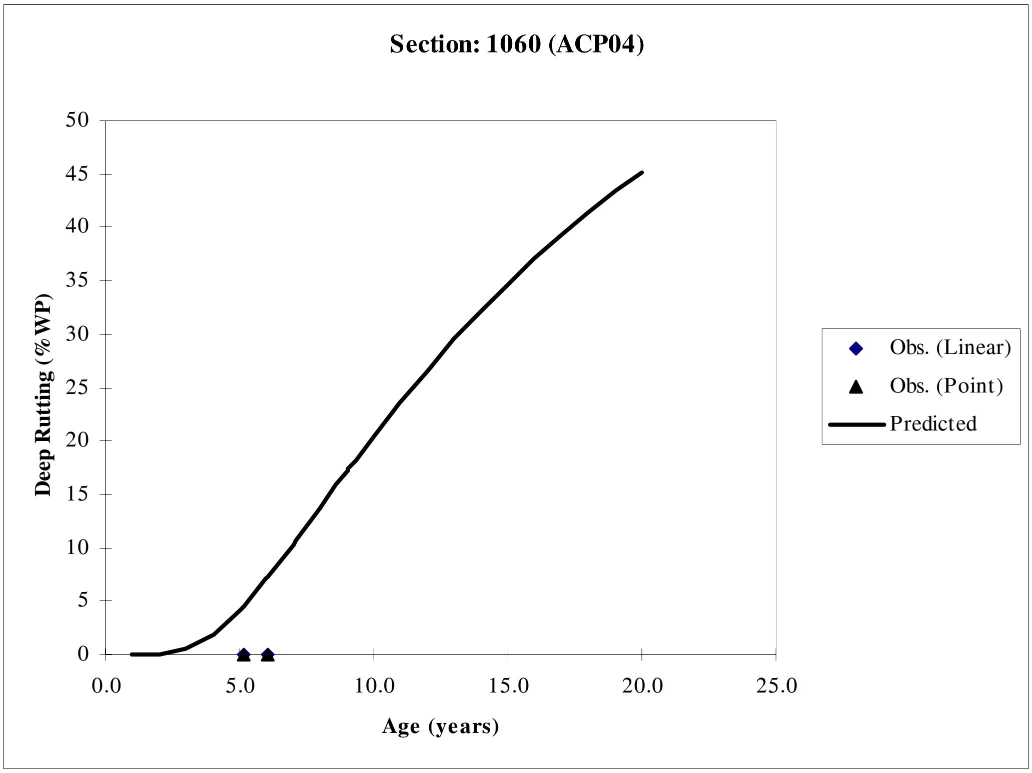


FIGURE D.48 Deep Rutting Observed Versus Predicted for Section 1060 using PMIS Model

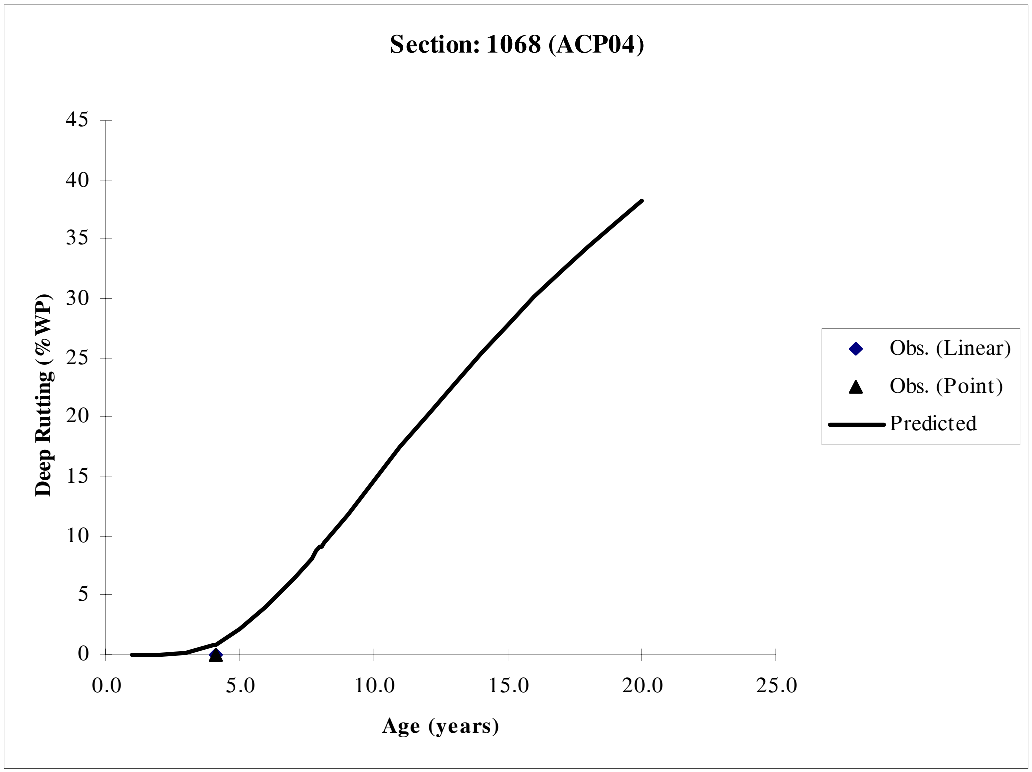


FIGURE D.49 Deep Rutting Observed Versus Predicted for Section 1068 using PMIS Model

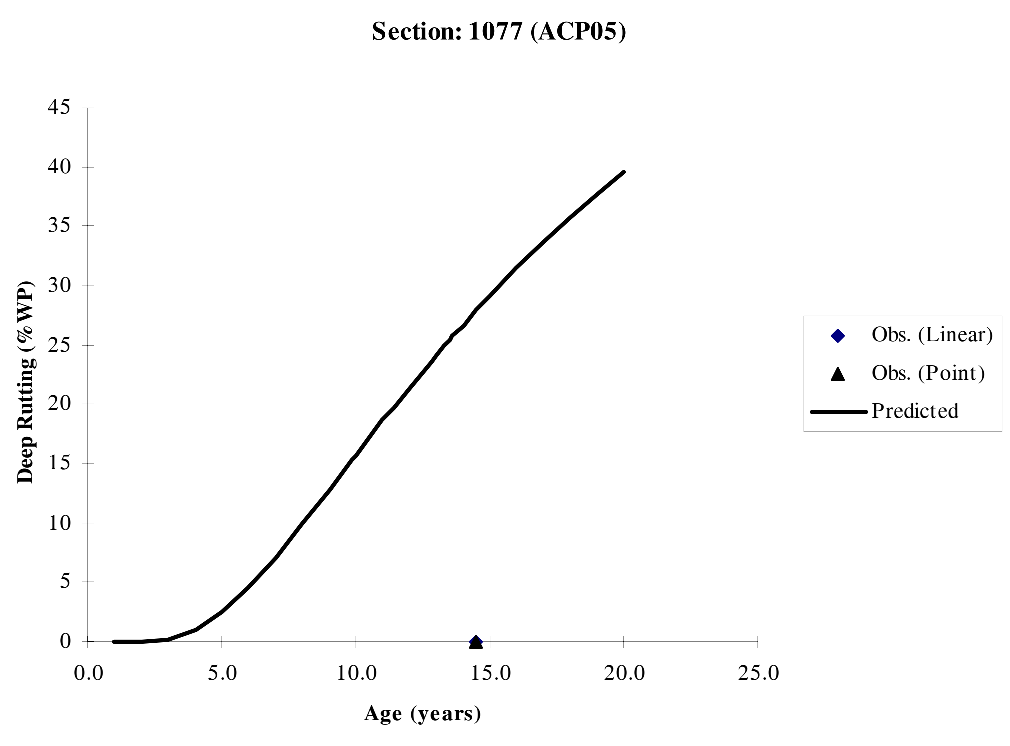


FIGURE D.50 Deep Rutting Observed Versus Predicted for Section 1077 using PMIS Model

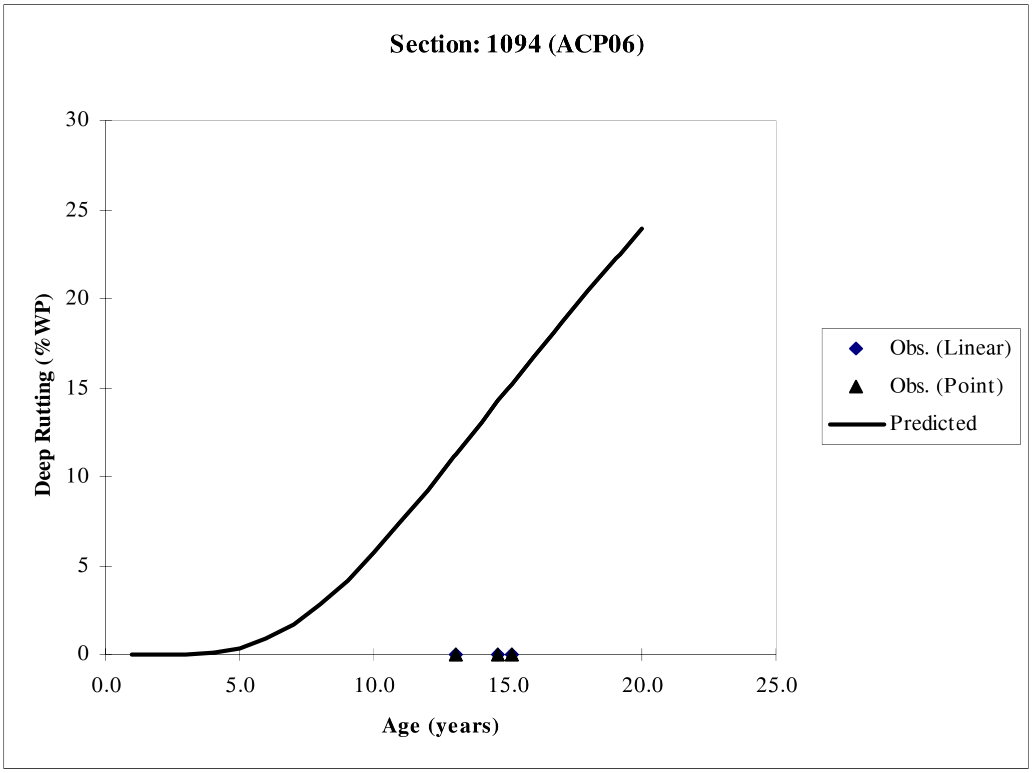


FIGURE D.51 Deep Rutting Observed Versus Predicted for Section 1094 using PMIS Model

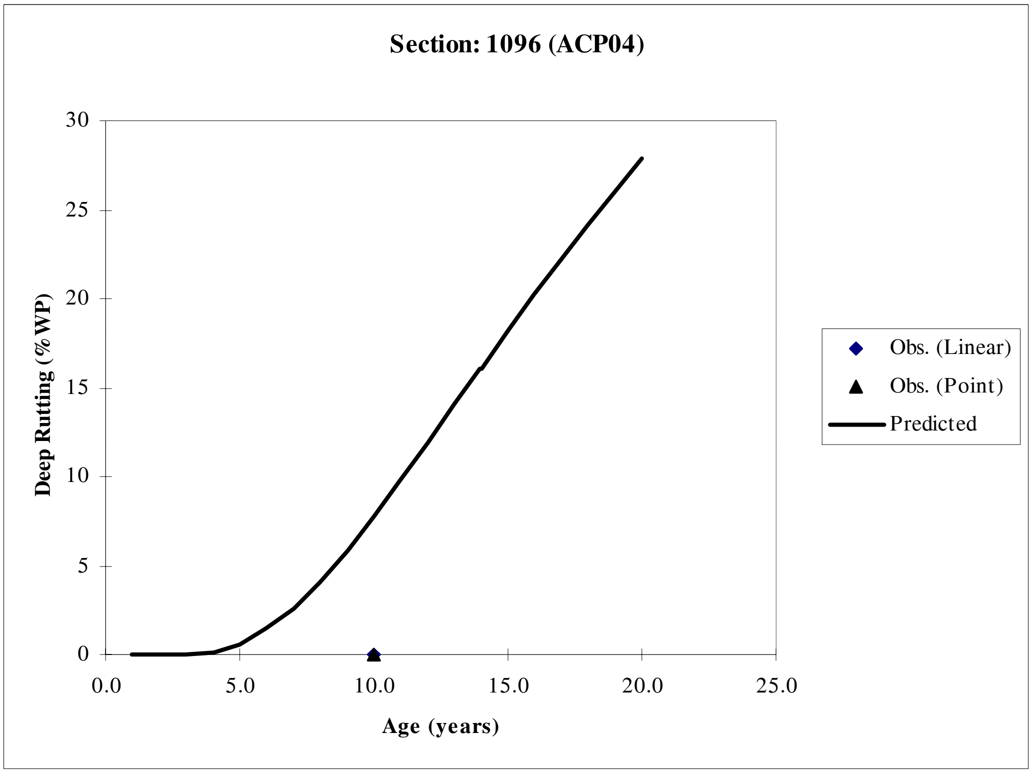


FIGURE D. 52 Deep Rutting Observed Versus Predicted for Section 1096 using PMIS Model

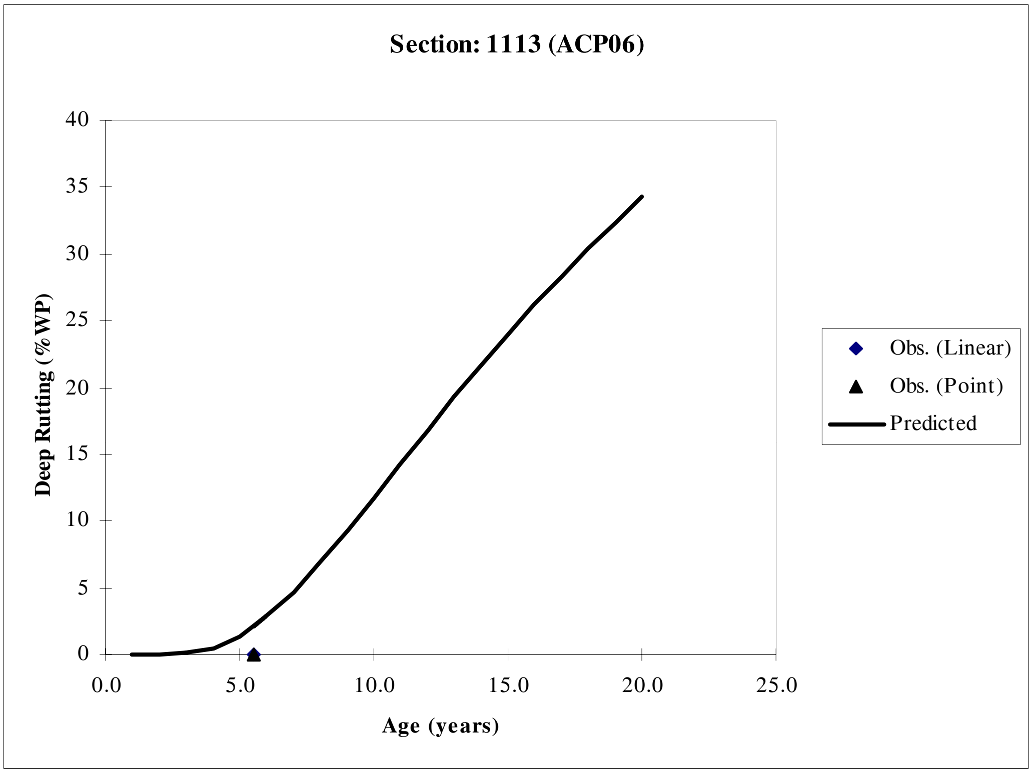


FIGURE D.53 Deep Rutting Observed Versus Predicted for Section 1113 using PMIS Model

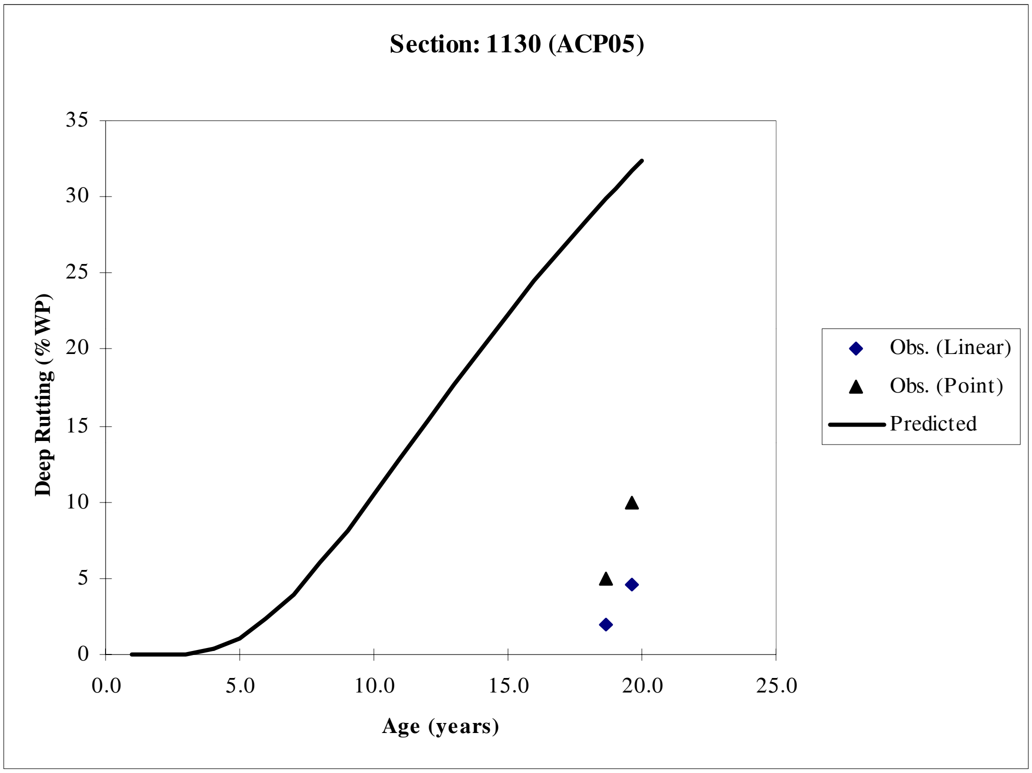


FIGURE D.54 Deep Rutting Observed Versus Predicted for Section 1130 using PMIS Model

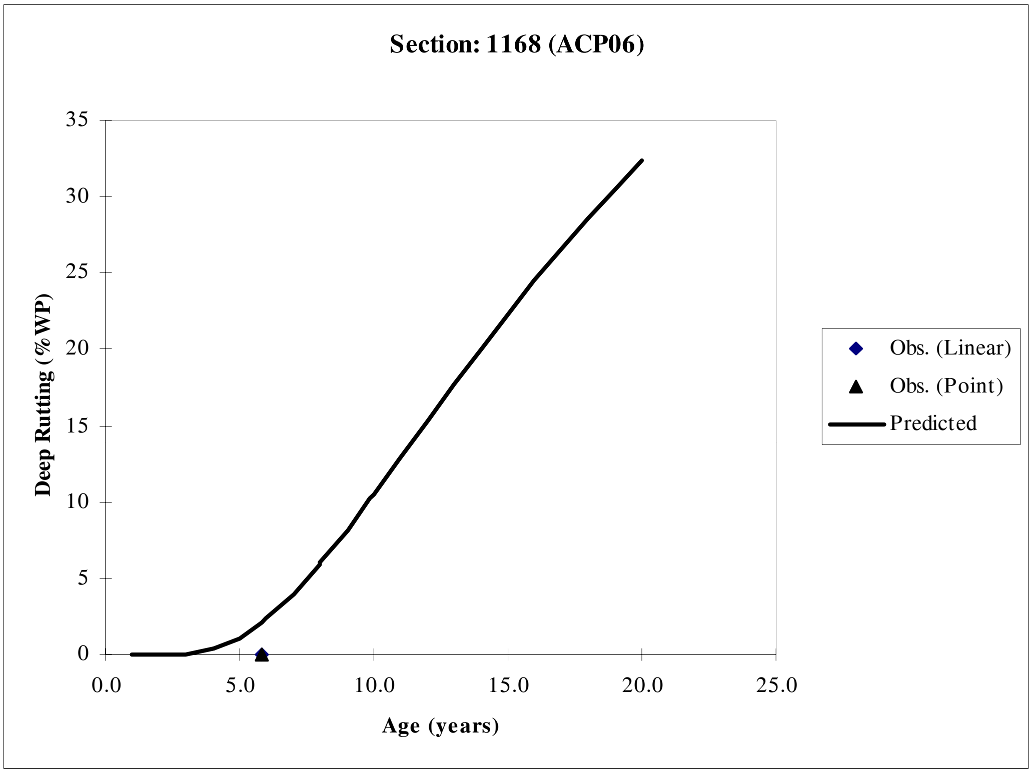


FIGURE D.55 Deep Rutting Observed Versus Predicted for Section 1168 using PMIS Model

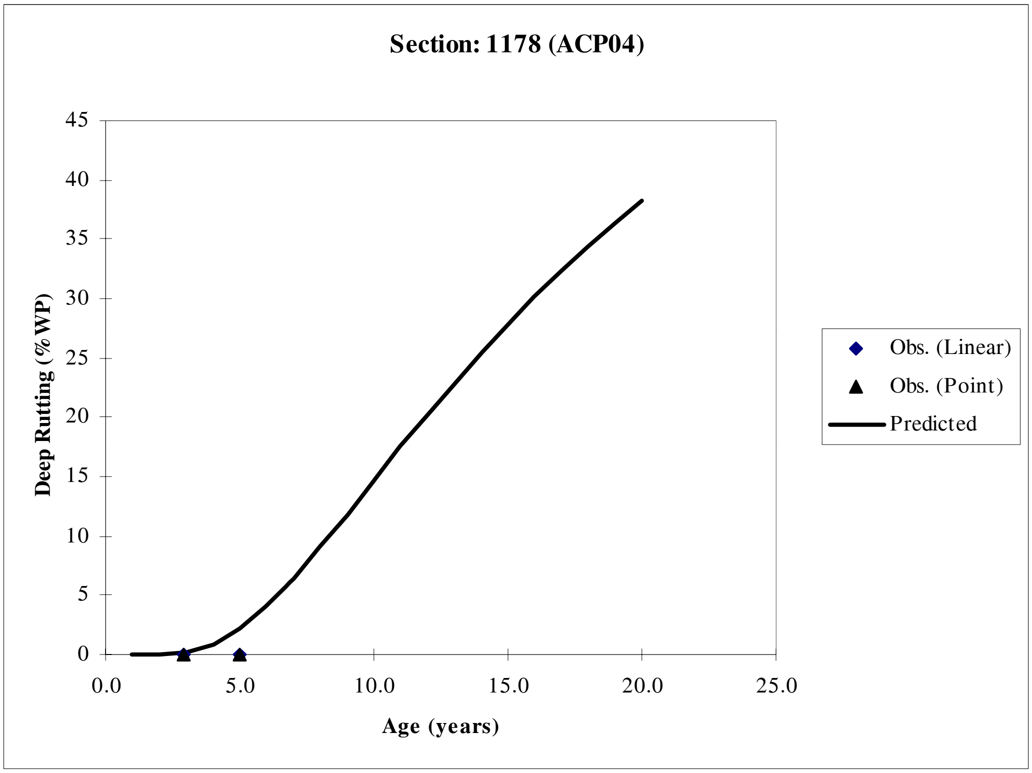


FIGURE D.56 Deep Rutting Observed Versus Predicted for Section 1178 using PMIS Model

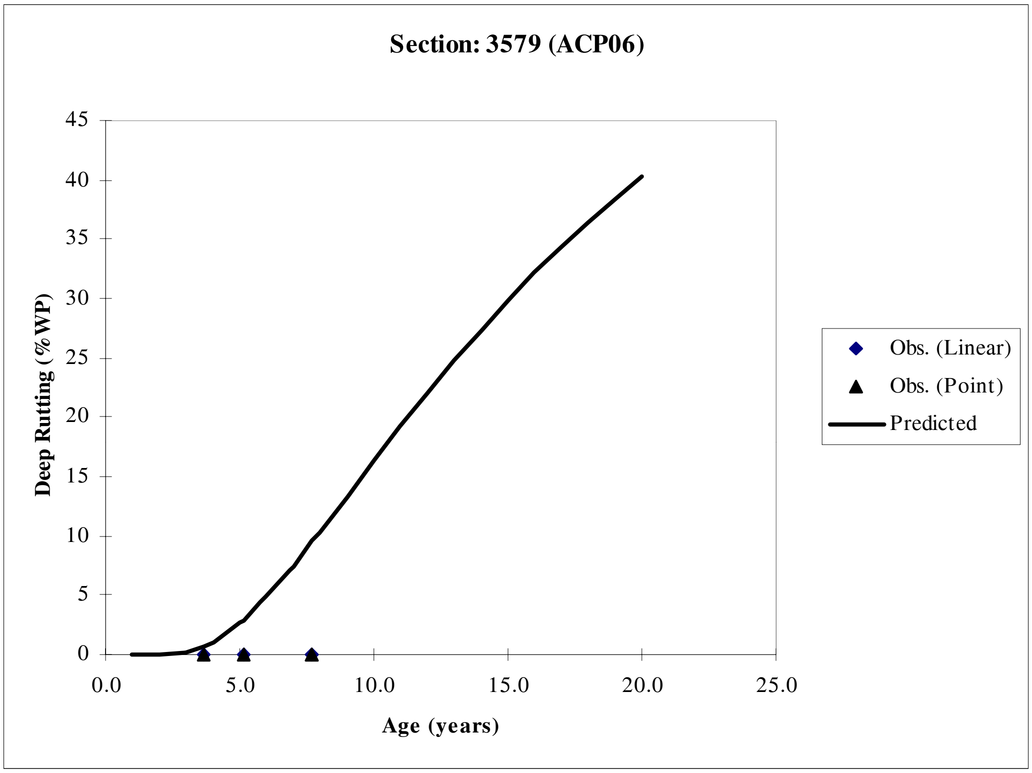


FIGURE D.57 Deep Rutting Observed Versus Predicted for Section 3579 using PMIS Model

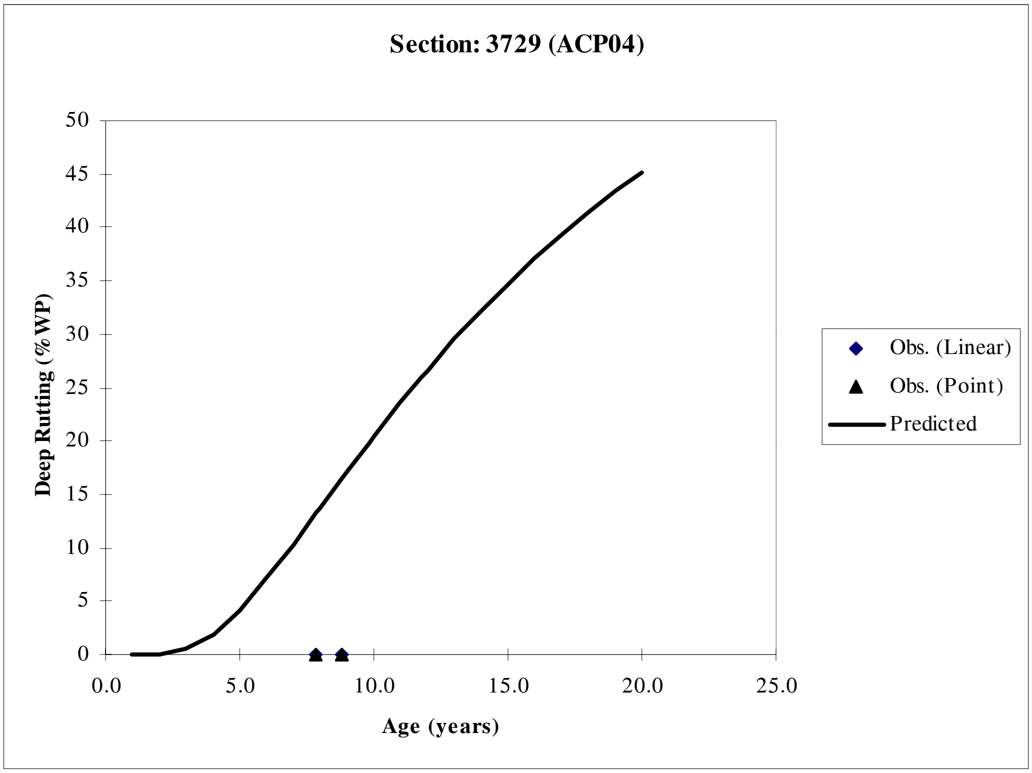


FIGURE D.58 Deep Rutting Observed Versus Predicted for Section 3729 using PMIS Model

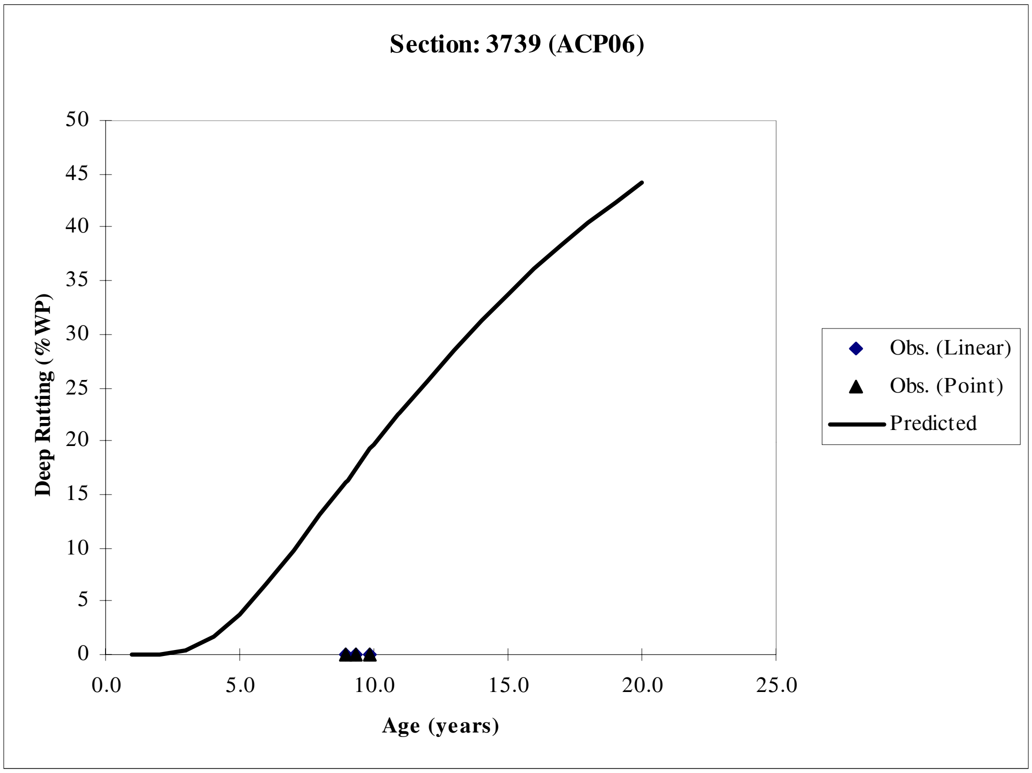


FIGURE D.59 Deep Rutting Observed Versus Predicted for Section 3739 using PMIS Model

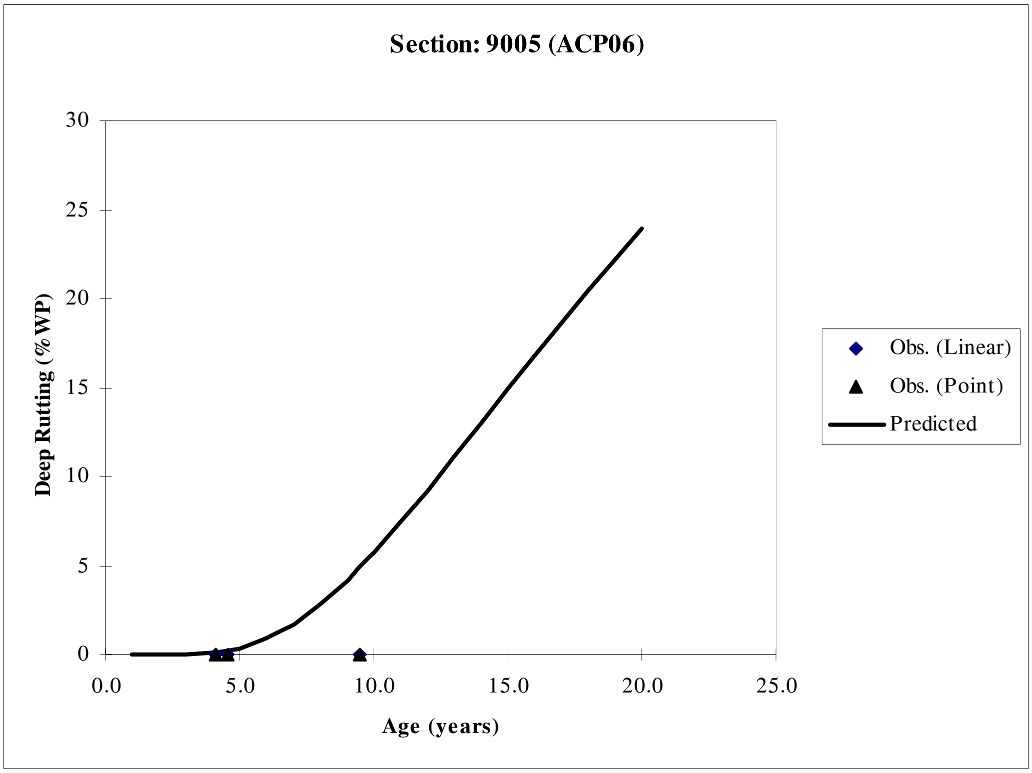


FIGURE D.60 Deep Rutting Observed Versus Predicted for Section 9005 using PMIS Model

APPENDIX E

HYPOTHESES TESTING FOR EACH SECTION

TABLE E.1 Analysis of TxDOT-PMIS Ride Quality Models

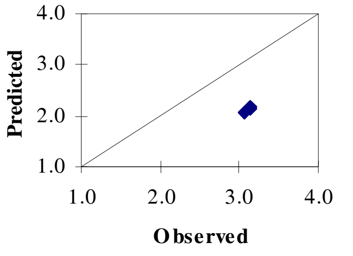
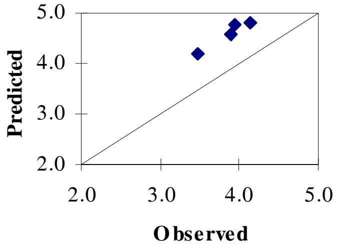
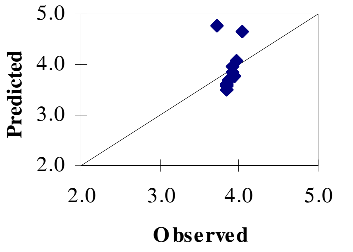
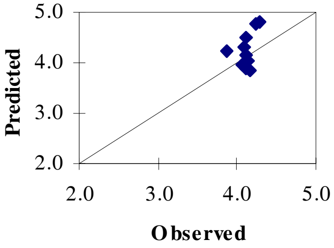
SHRP	Age	Ride Quality		Departure	Percent	Graph of	TESTING OF HYPOTHESES / REMARKS				
ID		Observed	Predicted	(obs-pre)	Departure	Observed Vs. Predicted Ride Quality	Null Hypothesis (H_0)	B_0=0	B_1=1	Null Hypothesis (H_0)	r=0
	years							(Intercept)	(Slope)		(corr.coef.)
1047	19.3	3.135	2.192	0.943	43.0		Regression Coeffs	-2.135	1.371	Correlation coeff.(r)	0.905
	20.4	3.133	2.130	1.003	47.1		Standard Error	2.005	0.645	t-statistic	2.125
	21.9	3.055	2.055	1.001	48.7		t-statistic	-1.065	0.575	Degeess of freedom	1
							Degrees of freedom	1	1	p-value (Prob>| r |)	0.280
							p value (Prob>| t |)	0.480	0.668	Reject H_0?	Can't
							Upper 95%	23.343	9.569	**Remarks:**	
							Lower 95%	-27.613	-6.827	o Inadequate data for analysis.	
							Reject H_0?	Can't	Can't	o Mean departure is too large.	
							Regression Statistics:			o Trends are parallel.	
							R square =		0.8187	o FIG D.1 suggests a shift.	
			Mean =	0.982	46.3		Root MSE =		0.0413		
			Std. Deviation =	0.034	2.9		Observations =		3		
1050	4.7	4.130	4.796	-0.666	-13.9		Regression Coeffs	0.692	1.007	Correlation coeff.	0.970
	5.8	3.942	4.760	-0.819	-17.2		Standard Error	0.689	0.178	t-statistic	5.654
	7.3	3.889	4.581	-0.693	-15.1		t-statistic	1.004	0.039	Degrees of freedom	2
	9.3	3.487	4.183	-0.696	-16.6		Degrees of freedom	2	2	p-value (Prob>| r |)	0.030
							p value (Prob>| t |)	0.421	0.973	Reject H_0?	Reject
							Upper 95%	3.656	1.773	**Remarks:**	
							Lower 95%	-2.273	0.241	o Inadequate data for analysis.	
							Reject H_0?	Can't	Can't	o Analyses indicate good	
							Regression Statistics:			correlation.	
							R square =		0.9411	o Mean departure is large.	
			Mean =	-0.718	-15.7		Root MSE =		0.0834	o Trends are parallel.	
			Std. Deviation =	0.068	1.5		Observations =		4	o FIG D.2 suggests a shift.	
1060	4.1	3.720	4.776	-1.056	-22.1		Regression Coeffs	2.505	0.371	Correlation coeff.	0.076
	5.1	4.045	4.653	-0.607	-13.1		Standard Error	6.730	1.729	t-statistic	0.215
	7.4	3.977	4.066	-0.088	-2.2		t-statistic	0.372	-0.364	Degrees of freedom	8
	7.8	3.921	3.948	-0.026	-0.7		Degrees of freedom	8	8	p-value (Prob>| r |)	0.836
	8.1	3.917	3.845	0.072	1.9		p-value (Prob>| t |)	0.719	0.725	Reject H_0?	Can't
	8.4	3.935	3.779	0.156	4.1		Upper 95%	18.024	4.358	**Remarks:**	
	8.7	3.874	3.699	0.174	4.7		Lower 95%	-13.014	-3.616	o Close prediction.	
	8.9	3.846	3.634	0.211	5.8		Reject H_0?	Can't	Can't	o Poor Correlation.	
	9.1	3.836	3.567	0.269	7.5		Regression Statistics:			o Trends don't match.	
	9.3	3.844	3.518	0.326	9.3		R square =		0.0057	o FIG D.3 suggests a flatter	
			Mean =	-0.057	-0.5		Root MSE =		0.4630	trend.	
			Std. Deviation =	0.440	9.9		Observations =		10		

TABLE E.1 Analysis of TxDOT-PMIS Ride Quality Models (Continued)

SHRP ID	Age (years)	Ride Quality Observed	Ride Quality Predictec	Departure (obs-pre)	Percent Departure
1068	2.9	4.275	4.800	-0.525	-10.9
	4.4	4.239	4.762	-0.523	-11.0
	6.0	4.108	4.482	-0.374	-8.3
	6.6	4.096	4.320	-0.225	-5.2
	6.9	3.879	4.217	-0.338	-8.0
	7.1	4.125	4.144	-0.019	-0.5
	7.4	4.151	4.049	0.103	2.5
	7.6	4.060	3.975	0.084	2.1
	7.9	4.109	3.891	0.218	5.6
	8.1	4.161	3.834	0.327	8.5
			Mean =	-0.127	-2.5
			Std. Deviation =	0.310	7.1

Graph of Observed Vs. Predicted Ride Quality

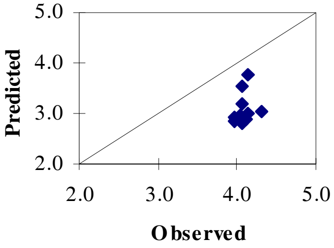


TESTING OF HYPOTHESES / REMARKS

Null Hypothesis (H_0)	$B_0=0$ (Intercept)	$B_1=1$ (Slope)	Null Hypothesis (H_0)	r=0 (corr.coef.)
Regression Coeffs	-1.590	1.417	Correlation coeff.	0.443
Standard Error	4.176	1.013	t-statistic	1.398
t-statistic	-0.381	0.411	Degrees of freedom	8
Degrees of freedom	8	8	p-value (Prob>| r |)	0.200
p-value (Prob>| t |)	0.713	0.692	Reject H_0?	Can't
Upper 95%	8.039	3.753		
Lower 95%	-11.219	-0.919		
Reject H_0?	Can't	Can't		
Regression Statistics:				
	R square =	0.1964		
	Root MSE =	0.3253		
	Observations =	10		

Remarks:
- o Pretty close prediction.
- o Trends don't match.
- o FIG D.4 suggests a flatter trend.

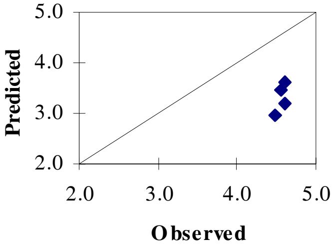
SHRP ID	Age (years)	Ride Quality Observed	Ride Quality Predictec	Departure (obs-pre)	Percent Departure
1077	8.8	4.147	3.787	0.361	9.5
	9.9	4.075	3.522	0.553	15.7
	11.3	4.071	3.187	0.884	27.7
	12.0	4.311	3.056	1.255	41.1
	12.3	4.141	3.005	1.136	37.8
	12.5	4.047	2.966	1.080	36.4
	12.8	3.978	2.921	1.057	36.2
	13.0	4.112	2.882	1.230	42.7
	13.3	3.968	2.840	1.128	39.7
	13.5	4.074	2.813	1.260	44.8
			Mean =	0.994	33.2
			Std. Deviation =	0.308	11.9



Null Hypothesis (H_0)	$B_0=0$ (Intercept)	$B_1=1$ (Slope)	Null Hypothesis (H_0)	r=0 (corr.coef.)
Regression Coeffs	-0.448	0.866	Correlation coeff.	0.265
Standard Error	4.568	1.116	t-statistic	0.776
t-statistic	-0.098	-0.120	Degrees of freedom	8
Degrees of freedom	8	8	p-value (Prob>| r |)	0.460
p-value (Prob>| t |)	0.924	0.908	Reject H_0?	Can't
Upper 95%	10.086	3.440		
Lower 95%	-10.981	-1.707		
Reject H_0?	Can't	Can't		
Regression Statistics:				
	R square =	0.0701		
	Root MSE =	0.3261		
	Observations =	10		

Remarks:
- o Mean and std. deviation of departure are very large.
- o Trends don't match.
- o FIG D.5 suggests a flatter trend.

SHRP ID	Age (years)	Ride Quality Observed	Ride Quality Predictec	Departure (obs-pre)	Percent Departure
1094	13.6	4.618	3.625	0.993	27.4
	14.7	4.556	3.443	1.113	32.3
	16.4	4.613	3.187	1.426	44.7
	18.0	4.489	2.978	1.511	50.7
			Mean =	1.261	38.8
			Std. Deviation =	0.247	10.8



Null Hypothesis (H_0)	$B_0=0$ (Intercept)	$B_1=1$ (Slope)	Null Hypothesis (H_0)	r=0 (corr.coef.)
Regression Coeffs	-11.319	3.202	Correlation coeff.	0.679
Standard Error	11.196	2.450	t-statistic	1.307
t-statistic	-1.011	0.898	Degrees of freedom	2
Degrees of freedom	2	2	p-value (Prob>| r |)	0.321
p-value (Prob>| t |)	0.418	0.464	Reject H_0?	Can't
Upper 95%	36.854	13.744		
Lower 95%	-59.493	-7.341		
Reject H_0?	Can't	Can't		
Regression Statistics:				
	R square =	0.4605		
	Root MSE =	0.2554		
	Observations =	4		

Remarks:
- o Inadequate data for analysis.
- o Mean and std. deviation of departure are very large.
- o Trends don't match.
- o FIG D.6 suggests a flatter trend.

TABLE E.1 Analysis of TxDOT-PMIS Ride Quality Models (Continued)

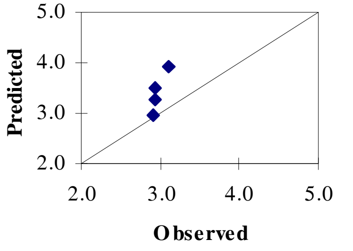
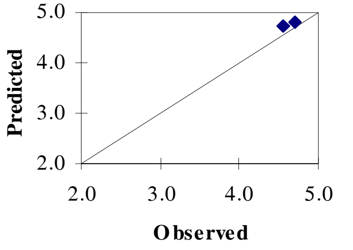
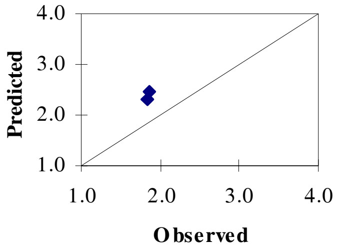
SHRP ID	Age	Ride Quality Observed	Ride Quality Predicted	Departure (obs-pre)	Percent Departure	Graph of Observed Vs. Predicted Ride Quality	TESTING OF HYPOTHESES / REMARKS Null Hypothesis (H_0)	$B_0=0$	$B_1=1$	Null Hypothesis (H_0)	$r=0$
	years							(Intercept)	(Slope)		(corr.coef.)
1096	9.0	3.103	3.922	-0.819	-20.9		Regression Coeffs	-7.848	3.799	Correlation coeff.	0.859
	10.7	2.925	3.506	-0.582	-16.6		Standard Error	4.740	1.598	t-statistic	2.378
	11.7	2.923	3.282	-0.360	-11.0		t-statistic	-1.656	1.752	Degrees of freedom	2
	13.5	2.914	2.962	-0.048	-1.6		Degrees of freedom	2	2	p-value (Prob>| r |)	0.141
							p-value (Prob>| t |)	0.240	0.222	Reject H_0?	Can't
							Upper 95%	12.546	10.672	**Remarks:** o Inadequate data for analysis. o Mean and std. deviation of departure are large. o Trends don't match. o FIG D.7 suggests a flatter trend.	
							Lower 95%	-28.242	-3.075		
							Reject H_0?	Can't	Can't		
							Regression Statistics:				
							R square =		0.7387		
			Mean =	-0.452	-12.5		Root MSE =		0.2524		
			Std. Deviation =	0.328	8.3		Observations =		4		
1113	4.3	4.700	4.799	-0.099	-2.1		Regression Coeffs			Correlation coeff.	
	6.0	4.549	4.738	-0.188	-4.0		Standard Error			t-statistic	
							t-statistic			Degrees of freedom	
							Degrees of freedom			p-value (Prob>| r |)	
							p-value (Prob>| t |)				
							Upper 95%			**Remarks:** o Hypothesis testing is not possible due to lack of data. o Pretty close prediction. o FIG D.8 suggests a small shift	
							Lower 95%				
							Regression Statistics:				
							R square =				
			Mean =	-0.143	-3.0		Root MSE =				
			Std. Deviation =	0.063	1.4		Observations =		2		
1130	17.7	1.857	2.446	-0.590	-24.1		Regression Coeffs			Correlation coeff.	
	19.6	1.829	2.291	-0.462	-20.2		Standard Error			t-statistic	
							t-statistic			Degrees of freedom	
							Degrees of freedom			p-value (Prob>| r |)	
							p-value (Prob>| t |)				
							Upper 95%			**Remarks:** o Hypothesis testing is not possible due to lack of data. o Mean departure is large. o Trends are almost parallel. o FIG D.9 suggests a shift.	
							Lower 95%				
							Regression Statistics:				
							R square =				
			Mean =	-0.526	-22.1		Root MSE =				
			Std. Deviation =	0.090	2.8		Observations =		2		

TABLE E.1 Analysis of TxDOT-PMIS Ride Quality Models (Continued)

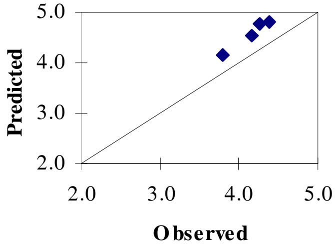
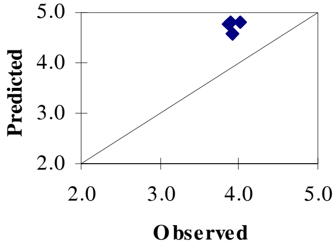
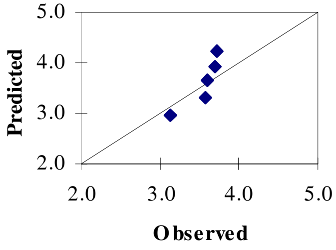
SHRP	Age	Ride Quality		Departure	Percent	Graph of	TESTING OF HYPOTHESES / REMARKS				
ID		Observed	Predicted	(obs-pre)	Departure	Observed Vs. Predicted Ride Quality	Null Hypothesis (H_0)	B_0=0	B_1=1	Null Hypothesis (H_0)	r=0
	years							(Intercept)	(Slope)		(corr.coef.)
1168	4.6	4.396	4.797	-0.402	-8.4		Regression Coeffs	-0.241	1.157	Correlation coeff.	0.973
	5.6	4.252	4.777	-0.526	-11.0		Standard Error	0.803	0.193	t-statistic	5.988
	7.7	4.166	4.530	-0.364	-8.0		t-statistic	-0.300	0.811	Degrees of freedom	2
	9.5	3.798	4.147	-0.349	-8.4		Degrees of freedom	2	2	p-value (Prob>| r |)	0.027
							p-value (Prob>| t |)	0.793	0.502	Reject H_0?	Reject
							Upper 95%	3.215	1.988	**Remarks:**	
							Lower 95%	-3.697	0.326	o Analysis is inappropriate due to inadequate data.	
							Reject H_0?	Can't	Can't		
							Regression Statistics:			o Good Correlation.	
								R square =	0.9472	o Pretty close prediction.	
			Mean =	-0.410	-9.0			Root MSE =	0.0853	o Trends are almost parallel.	
			Std. Deviation =	0.080	1.4			Observations =	4	o FIG D.10 suggests a shift.	
3579	2.8	4.011	4.800	-0.789	-16.4		Regression Coeffs	3.393	0.344	Correlation coeff.	0.214
	3.4	3.902	4.800	-0.898	-18.7		Standard Error	4.354	1.110	t-statistic	0.309
	5.3	3.863	4.773	-0.909	-19.1		t-statistic	0.779	-0.591	Degrees of freedom	2
	7.0	3.910	4.590	-0.680	-14.8		Degrees of freedom	2	2	p-value (Prob>| r |)	0.786
							p-value (Prob>| t |)	0.517	0.614	Reject H_0?	Can't
							Upper 95%	22.128	5.120	**Remarks:**	
							Lower 95%	-15.341	-4.433	o Analysis is inappropriate due to inadequate data.	
							Reject H_0?	Can't	Can't		
							Regression Statistics:			o Mean departure is large.	
								R square =	0.0457	o Trends are almost parallel.	
			Mean =	-0.819	-17.3			Root MSE =	0.1213	o FIG D.12 suggests a shift.	
			Std. Deviation =	0.107	2.0			Observations =	4		
3729	6.8	3.724	4.234	-0.510	-12.0		Regression Coeffs	-2.925	1.845	Correlation coeff.	0.880
	7.9	3.695	3.921	-0.226	-5.8		Standard Error	2.043	0.575	t-statistic	3.209
	8.8	3.609	3.658	-0.049	-1.3		t-statistic	-1.431	1.470	Degrees of freedom	3
	10.2	3.565	3.307	0.258	7.8		Degrees of freedom	3	3	p-value (Prob>| r |)	0.049
	11.8	3.140	2.978	0.163	5.5		p-value (Prob>| t |)	0.248	0.238	Reject H_0?	Reject
							Upper 95%	3.578	3.675	**Remarks:**	
							Lower 95%	-9.427	0.015	o Analysis is inappropriate due to inadequate data.	
							Reject H_0?	Can't	Can't		
							Regression Statistics:			o Pretty close prediction.	
								R square =	0.7743	o Good correlation.	
			Mean =	-0.073	-1.2			Root MSE =	0.2714	o Trends don't match.	
			Std. Deviation =	0.308	8.1			Observations =	5		

TABLE E.1 Analysis of TxDOT-PMIS Ride Quality Models (Continued)

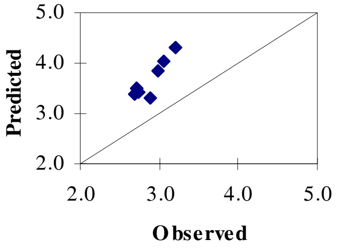
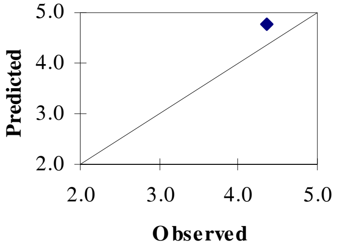
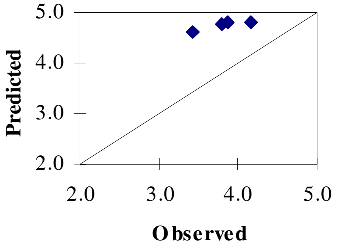
SHRP	Age	Ride Quality		Departure	Percent	Graph of	TESTING OF HYPOTHESES / REMARKS				
ID		Observed	Predicted	(obs-pre)	Departure	Observed Vs. Predicted Ride Quality	Null Hypothesis (H_0)	B_0=0	B_1=1	Null Hypothesis (H_0)	r=0
	years							(Intercept)	(Slope)		(corr.coef.)
3739	7.9	3.215	4.311	-1.096	-25.4		Regression Coeffs	-1.452	1.774	Correlation coeff.	0.911
	9.0	3.048	4.054	-1.007	-24.8		Standard Error	1.044	0.360	t-statistic	4.935
	9.9	2.993	3.828	-0.836	-21.8		t-statistic	-1.390	2.153	Degrees of freedom	5
	11.3	2.725	3.513	-0.788	-22.4		Degrees of freedom	5	5	p-value (Prob>| r |)	0.004
	11.6	2.727	3.438	-0.711	-20.7		p-value (Prob>| t |)	0.223	0.084	Reject H_0?	Reject
	12.0	2.700	3.366	-0.666	-19.8		Upper 95%	1.232	2.698	**Remarks:** o Analysis is inappropriate due to inadequate data. o Mean departure is too large. o FIG D.14 suggests a flatter trend.	
	12.2	2.881	3.321	-0.440	-13.3		Lower 95%	-4.135	0.850		
							Reject H_0?	Can't	Can't		
							Regression Statistics:				
							R square =		0.8296		
			Mean =	-0.792	-21.2		Root MSE =		0.1726		
			Std. Deviation =	0.219	4.1		Observations =		7		
3875	5.3	4.353	4.766	-0.413	-8.7		Regression Coeffs			Correlation coeff.	
							Standard Error			t-statistic	
							t-statistic			Degrees of freedom	
							Degrees of freedom			p-value (Prob>| r |)	
							p-value (Prob>| t |)			Reject H_0?	
							Upper 95%			**Remarks:** o Hypothesis testing is not possible due to lack of data. o Close prediction.	
							Lower 95%				
							Reject H_0?				
							Regression Statistics:				
							R square =				
			Mean =	-0.413	-8.7		Root MSE =				
			Std. Deviation =	-	-		Observations =		1		
9005	3.6	4.159	4.800	-0.641	-13.4		Regression Coeffs	3.633	0.291	Correlation coeff.	0.898
	4.6	3.880	4.800	-0.920	-19.2		Standard Error	0.384	0.100	t-statistic	2.894
	6.3	3.797	4.770	-0.973	-20.4		t-statistic	9.458	-7.065	Degrees of freedom	2
	8.1	3.431	4.598	-1.167	-25.4		Degrees of freedom	2	2	p-value (Prob>| r |)	0.102
							p-value (Prob>| t |)	0.011	0.019	Reject H_0?	Can't
							Upper 95%	5.285	0.723	**Remarks:** o Analysis is inappropriate due to inadequate data. o Mean departure is large. o Poor prediction. o Trends are almost parallel. o FIG D.16 suggests a shift.	
							Lower 95%	1.980	-0.141		
							Reject H_0?	Reject	Reject		
							Regression Statistics:				
							R square =		0.8073		
			Mean =	-0.925	-19.6		Root MSE =		0.0522		
			Std. Deviation =	0.217	4.9		Observations =		4		

TABLE E.2 Analysis of TxDOT-PMIS Alligator Cracking Models

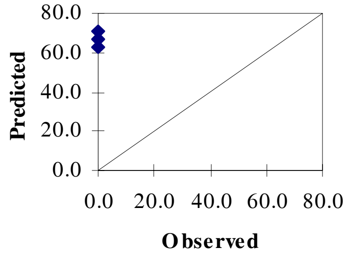
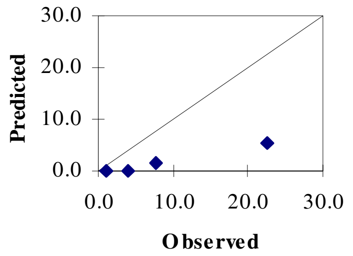
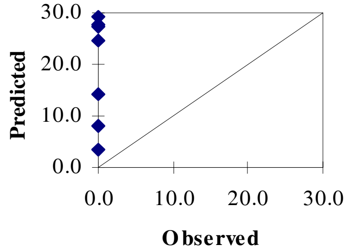
SHRP	Age	Alligator Cracking		Departure	Percent	Graph of	TESTING OF HYPOTHESES / REMARKS				
ID		Observed	Predicted	(obs-pre)	Departure	Observed Vs. Predicted Alligator Cracking	Null Hypothesis (H_0)	B_0=0	B_1=1	Null Hypothesis (H_0)	r=0
	years							(Intercept)	(Slope)		(corr.coef.)
1047	20.0	0.000	62.840	-62.840	-100.0		Regression Coeffs			Correlation coeff.(r)	
	21.9	0.000	67.221	-67.221	-100.0		Standard Error			t-statistic	
	24.1	0.000	71.376	-71.376	-100.0		t-statistic			Degeess of freedom	
							Degrees of freedom			p-value (Prob>| r |)	
							p value (Prob>| t |)			Reject H_0?	
							Upper 95%			**Remarks:**	
							Lower 95%			o Hypotheses can't be tested	
							Reject H_0?			due to observed data trend.	
							Regression Statistics:			o Mean departure is too large.	
								R square =		o Poor prediction.	
			Mean =	-67.146	-100.0			Root MSE =			
			Std. Deviation =	4.269	0.0			Observations =	3		
1050	5.4	4.015	0.021	3.994	18885.3		Regression Coeffs	-0.601	0.259	Correlation coeff.	0.991
	5.9	1.122	0.074	1.049	1427.0		Standard Error	0.297	0.024	t-statistic	10.601
	8.0	7.727	1.370	6.357	463.9		t-statistic	-2.027	-30.299	Degrees of freedom	2
	10.1	22.621	5.328	17.293	324.6		Degrees of freedom	2	2	p-value (Prob>| r |)	0.009
							p value (Prob>| t |)	0.180	0.001	Reject H_0?	Reject
							Upper 95%	0.675	0.364	**Remarks:**	
							Lower 95%	-1.877	0.154	o Inadequate data for analysis.	
							Reject H_0?	Can't	Reject	o Analyses indicate good	
							Regression Statistics:			correlation.	
								R square =	0.9825	o Mean departure is large.	
			Mean =	7.173	5275.2			Root MSE =	0.4047	o Trends don't match.	
			Std. Deviation =	7.087	9086.6			Observations =	4	o FIG D.18 suggests a steeper trend.	
1060	5.1	0.000	3.367	-3.367	-100.0		Regression Coeffs			Correlation coeff.	
	6.1	0.000	7.933	-7.933	-100.0		Standard Error			t-statistic	
	7.1	0.000	14.194	-14.194	-100.0		t-statistic			Degrees of freedom	
	8.6	0.000	24.593	-24.593	-100.0		Degrees of freedom			p-value (Prob>| r |)	
	9.0	0.000	27.439	-27.439	-100.0		p-value (Prob>| t |)			Reject H_0?	
	9.1	0.000	27.530	-27.530	-100.0		Upper 95%			**Remarks:**	
	9.3	0.000	29.080	-29.080	-100.0		Lower 95%			o Hypotheses can't be tested	
							Reject H_0?			due to observed data trend.	
							Regression Statistics:			o Mean and std. deviation of	
								R square =		departure are large.	
			Mean =	-19.162	-100.0			Root MSE =		o Trends don't match.	
			Std. Deviation =	10.541	0.0			Observations =	7	o FIG D.19 suggests a flatter trend.	

TABLE E.2 Analysis of TxDOT-PMIS Alligator Cracking Models (Continued)

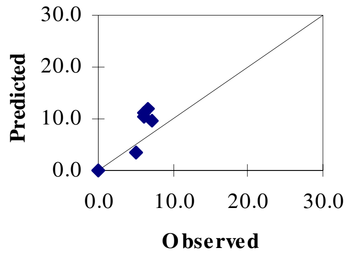
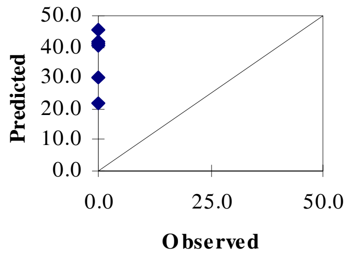
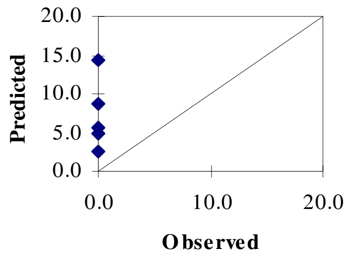
SHRP	Age	Alligator Cracking		Departure	Percent	Graph of	TESTING OF HYPOTHESES / REMARKS				
ID		Observed	Predicted	(obs-pre)	Departure	Observed Vs. Predicted Alligator Cracking	Null Hypothesis (H_0)	B_0=0	B_1=1	Null Hypothesis (H_0)	r=0
	years							(Intercept)	(Slope)		(corr.coef.)
1068	4.1	0.000	0.103	-0.103	-100.0		Regression Coeffs	-0.628	1.628	Correlation coeff.	0.883
	6.2	4.921	3.429	1.493	43.5		Standard Error	2.461	0.433	t-statistic	3.757
	7.7	7.037	9.428	-2.392	-25.4		t-statistic	-0.255	1.449	Degrees of freedom	4
	7.9	6.216	10.468	-4.252	-40.6		Degrees of freedom	4	4	p-value (Prob>| r |)	0.020
	8.0	6.216	11.255	-5.038	-44.8		p-value (Prob>| t |)	0.811	0.221	Reject H_0?	Reject
	8.1	6.519	11.869	-5.350	-45.1		Upper 95%	6.205	2.831	**Remarks:**	
							Lower 95%	-7.460	0.425	o Inadequate data.	
							Reject H_0?	Can't	Can't	o Fair correlation.	
							Regression Statistics:			o Close prediction.	
								R square =	0.7792		
				Mean =	-2.607	-35.4		Root MSE =	2.5371		
				Std. Deviation =	2.802	46.3		Observations =	6		
1077	9.9	0.000	21.898	-21.898	-100.0		Regression Coeffs			Correlation coeff.	
	11.4	0.000	30.443	-30.443	-100.0		Standard Error			t-statistic	
							t-statistic			Degrees of freedom	
	13.3	0.000	40.081	-40.081	-100.0		Degrees of freedom			p-value (Prob>| r |)	
	13.5	0.000	40.879	-40.879	-100.0		p-value (Prob>| t |)			Reject H_0?	
	13.6	0.000	41.503	-41.503	-100.0		Upper 95%			**Remarks:**	
	14.5	0.000	45.310	-45.310	-100.0		Lower 95%			o Hypotheses can't be tested	
							Reject H_0?			due to observed data trend.	
							Regression Statistics:			o Poor prediction.	
								R square =		o Trends don't match.	
				Mean =	-36.686	-100.0		Root MSE =			
				Std. Deviation =	8.767	0.0		Observations =	6		
1094	13.0	0.000	2.459	-2.459	-100.0		Regression Coeffs			Correlation coeff.	
	14.7	0.000	4.776	-4.776	-100.0		Standard Error			t-statistic	
	15.2	0.000	5.640	-5.640	-100.0		t-statistic			Degrees of freedom	
	16.7	0.000	8.685	-8.685	-100.0		Degrees of freedom			p-value (Prob>| r |)	
	19.1	0.000	14.409	-14.409	-100.0		p-value (Prob>| t |)			Reject H_0?	
							Upper 95%			**Remarks:**	
							Lower 95%			o Hypotheses can't be tested	
							Reject H_0?			due to observed data trend.	
							Regression Statistics:			o Mean and std. deviation of	
								R square =		departure are large.	
				Mean =	-7.194	-100.0		Root MSE =		o Trends don't match.	
				Std. Deviation =	4.609	0.0		Observations =	5		

TABLE E.2 Analysis of TxDOT-PMIS Alligator Cracking Models (Continued)

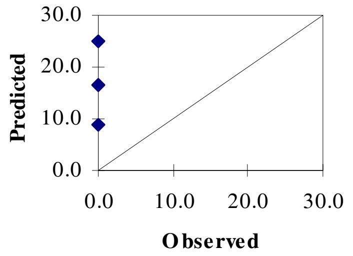
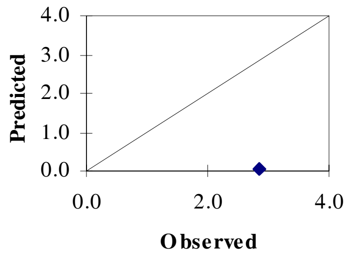
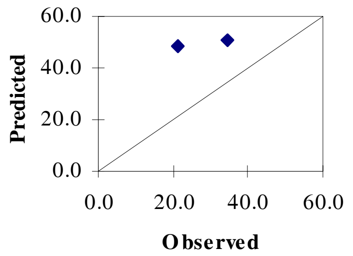
SHRP ID	Age	Alligator Cracking		Departure	Percent	Graph of	TESTING OF HYPOTHESES / REMARKS				
		Observed	Predicted	(obs-pre)	Departure	Observed Vs. Predicted Alligator Cracking	Null Hypothesis (H_0)	B_0=0	B_1=1	Null Hypothesis (H_0)	r=0
	years							(Intercept)	(Slope)		(corr.coef.)
1096	10.0	0.000	8.674	-8.674	-100.0		Regression Coeffs			Correlation coeff.	
	12.0	0.000	16.689	-16.689	-100.0		Standard Error			t-statistic	
	14.0	0.000	25.041	-25.041	-100.0		t-statistic			Degrees of freedom	
							Degrees of freedom			p-value (Prob>| r |)	
							p-value (Prob>| t |)			Reject H_0?	
							Upper 95%			**Remarks:** o Hypotheses can't be tested due to observed data trend. o Mean and std. deviation of departure are large. o Trends don't match.	
							Lower 95%				
							Reject H_0?				
							Regression Statistics:				
							R square =				
			Mean =	-16.801	-100.0		Root MSE =				
			Std. Deviation =	8.184	0.0		Observations =		3		
1113	6.4	2.849	0.064	2.786	4386.2		Regression Coeffs			Correlation coeff.	
							Standard Error			t-statistic	
							t-statistic			Degrees of freedom	
							Degrees of freedom			p-value (Prob>| r |)	
							p-value (Prob>| t |)				
							Upper 95%			**Remarks:** o Hypothesis testing is not possible due to lack of data. o Pretty close prediction.	
							Lower 95%				
							Regression Statistics:				
							R square =				
			Mean =	2.786	4386.2		Root MSE =				
			Std. Deviation =	-	-		Observations =		1		
1130	18.7	21.412	48.118	-26.706	-55.5		Regression Coeffs			Correlation coeff.	
	19.6	34.319	51.144	-16.825	-32.9		Standard Error			t-statistic	
							t-statistic			Degrees of freedom	
							Degrees of freedom			p-value (Prob>| r |)	
							p-value (Prob>| t |)				
							Upper 95%			**Remarks:** o Hypothesis testing is not possible due to lack of data. o Mean departure is large. o Trends don't match. o FIG D.25 suggests a steeper trend.	
							Lower 95%				
							Regression Statistics:				
							R square =				
			Mean =	-21.766	-44.2		Root MSE =				
			Std. Deviation =	6.987	16.0		Observations =		2		

TABLE E.2 Analysis of TxDOT-PMIS Alligator Cracking Models (Continued)

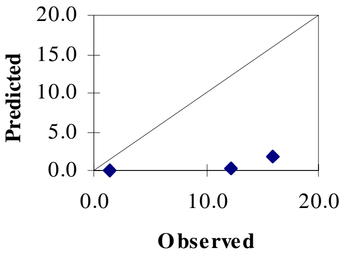
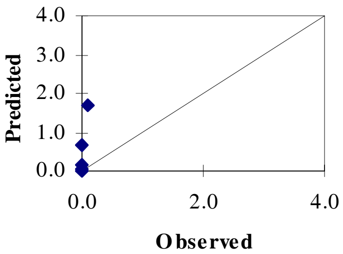
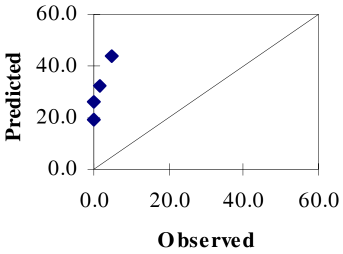
SHRP	Age	Alligator Cracking		Departure	Percent	Graph of	TESTING OF HYPOTHESES / REMARKS				
ID		Observed	Predicted	(obs-pre)	Departure	Observed Vs. Predicted Alligator Cracking	Null Hypothesis (H_0)	B_0=0	B_1=1	Null Hypothesis (H_0)	r=0
	years							(Intercept)	(Slope)		(corr.coef.)
1168	5.8	1.381	0.006	1.375	23024.6		Regression Coeffs	-0.316	0.108	Correlation coeff.	0.803
	8.0	12.174	0.325	11.849	3649.1		Standard Error	0.927	0.080	t-statistic	1.349
	9.9	15.929	1.899	14.031	738.9		t-statistic	-0.341	-11.164	Degrees of freedom	1
							Degrees of freedom	1	1	p-value (Prob>| r |)	0.406
							p-value (Prob>| t |)	0.791	0.057	Reject H_0?	Can't
							Upper 95%	11.466	1.123	**Remarks:**	
							Lower 95%	-12.098	-0.908	o Analysis is inappropriate	
							Reject H_0?	Can't	Can't	due to inadequate data.	
							Regression Statistics:			o Mean departure is large.	
							R square =		0.6453	o Trends don't match.	
			Mean =	9.085	9137.5		Root MSE =		0.8536	o FIG D.26 suggests a steeper trend.	
			Std. Deviation =	6.765	12114.2		Observations =		3		
3579	3.6	0.000	0.000	0.000	-100.0		Regression Coeffs	0.214	17.336	Correlation coeff.	0.922
	5.1	0.000	0.031	-0.031	-100.0		Standard Error	0.162	4.189	t-statistic	4.139
	5.8	0.000	0.132	-0.132	-100.0		t-statistic	1.321	3.900	Degrees of freedom	3
	6.9	0.000	0.691	-0.691	-100.0		Degrees of freedom	3	3	p-value (Prob>| r |)	0.026
	7.7	0.086	1.710	-1.624	-95.0		p-value (Prob>| t |)	0.278	0.030	Reject H_0?	Reject
							Upper 95%	0.728	30.667	**Remarks:**	
							Lower 95%	-0.301	4.005	o Analysis is inappropriate	
							Reject H_0?	Can't	Reject	due to inadequate data.	
							Regression Statistics:			o Pretty close prediction.	
							R square =		0.8509	o Good correlation.	
			Mean =	-0.496	-99.0		Root MSE =		0.3235		
			Std. Deviation =	0.690	2.3		Observations =		5		
3729	7.9	0.000	19.415	-19.415	-100.0		Regression Coeffs	23.050	4.378	Correlation coeff.	0.964
	8.8	0.000	25.830	-25.830	-100.0		Standard Error	2.225	0.853	t-statistic	5.135
	9.8	1.856	32.556	-30.700	-94.3		t-statistic	10.360	3.962	Degrees of freedom	2
	11.8	4.878	43.883	-39.005	-88.9		Degrees of freedom	2	2	p-value (Prob>| r |)	0.036
							p-value (Prob>| t |)	0.009	0.058	Reject H_0?	Reject
							Upper 95%	32.623	8.047	**Remarks:**	
							Lower 95%	13.476	0.710	o Analysis is inappropriate	
							Reject H_0?	Reject	Can't	due to inadequate data.	
							Regression Statistics:			o Mean departure is too large.	
							R square =		0.9295	o Good correlation.	
			Mean =	-28.738	-95.8		Root MSE =		3.4001	o Trends don't match.	
			Std. Deviation =	8.259	5.3		Observations =		4	o FIG D.29 suggests a flatter trend.	

TABLE E.2 Analysis of TxDOT-PMIS Alligator Cracking Models (Continued)

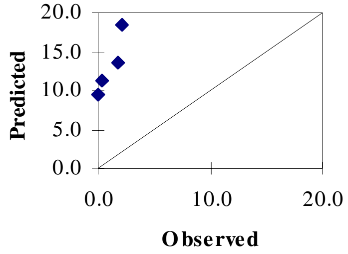
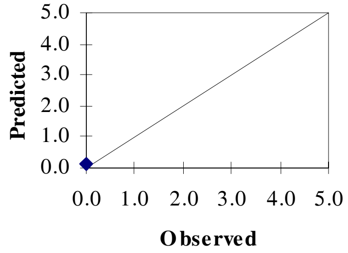
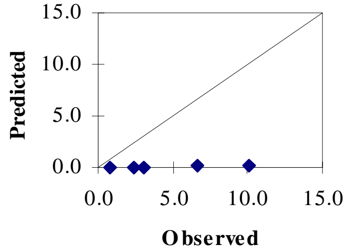
SHRP	Age	Alligator Cracking		Departure	Percent	Graph of	TESTING OF HYPOTHESES / REMARKS				
ID		Observed	Predicted	(obs-pre)	Departure	Observed Vs. Predicted Alligator Cracking	Null Hypothesis (H_0)	B_0=0	B_1=1	Null Hypothesis (H_0)	r=0
	years							(Intercept)	(Slope)		(corr.coef.)
3739	8.9	0.000	9.464	-9.464	-100.0		Regression Coeffs	9.606	3.415	Correlation coeff.	0.912
	9.3	0.302	11.159	-10.857	-97.3		Standard Error	1.518	1.083	t-statistic	3.152
	9.9	1.813	13.662	-11.849	-86.7		t-statistic	6.328	2.229	Degrees of freedom	2
	10.9	2.115	18.585	-16.469	-88.6		Degrees of freedom	2	2	p-value (Prob>| r |)	0.088
							p-value (Prob>| t |)	0.024	0.156	Reject H_0?	Can't
							Upper 95%	16.137	8.076	**Remarks:**	
							Lower 95%	3.074	-1.246	o Analysis is inappropriate	
							Reject H_0?	Reject	Can't	due to inadequate data.	
							Regression Statistics:			o Mean departure is large.	
								R square =	0.8324	o Trends don't match.	
			Mean =	-12.160	-93.2			Root MSE =	1.9913		
			Std. Deviation =	3.035	6.5			Observations =	4		
3875	5.6	0.000	0.107	-0.107	-100.0		Regression Coeffs			Correlation coeff.	
							Standard Error			t-statistic	
							t-statistic			Degrees of freedom	
							Degrees of freedom			p-value (Prob>| r |)	
							p-value (Prob>| t |)			Reject H_0?	
							Upper 95%			**Remarks:**	
							Lower 95%			o Hypothesis testing is not	
							Reject H_0?			possible due to lack of data.	
							Regression Statistics:			o Pretty close prediction.	
								R square =			
			Mean =	-0.107	-100.0			Root MSE =			
			Std. Deviation =	-	-			Observations =	1		
9005							Regression Coeffs	-0.058	0.032	Correlation coeff.	0.973
	4.6	0.777	0.000	0.777	*288429.1*		Standard Error	0.024	0.004	t-statistic	7.354
	5.0	3.022	0.000	3.022	*288429.1*		t-statistic	-2.370	-225.24	Degrees of freedom	3
	6.6	2.331	0.001	2.330	288429.1		Degrees of freedom	3	3	p-value (Prob>| r |)	0.005
	9.5	6.605	0.171	6.434	3759.9		p-value (Prob>| t |)	0.098	0.000	Reject H_0?	Reject
	9.9	10.145	0.262	9.883	3776.7		Upper 95%	0.020	0.045	**Remarks:**	
							Lower 95%	-0.136	0.018	o Analysis is inappropriate	
							Reject H_0?	Can't	Reject	due to inadequate data.	
							Regression Statistics:			o Fair correlation.	
								R square =	0.9474	o Trends don't match.	
			Mean =	4.489	174564.8			Root MSE =	0.0325	o FIG D.32 suggests a steeper trend.	
			Std. Deviation =	3.656	155915.1			Observations =	5		

TABLE E.3 Analysis of TxDOT-PMIS Alligator Cracking Models (A+L)

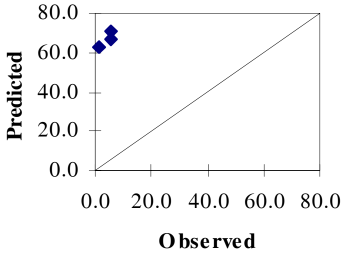
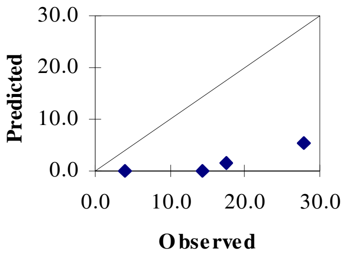
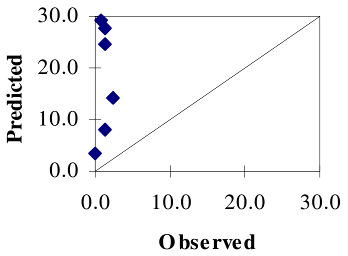
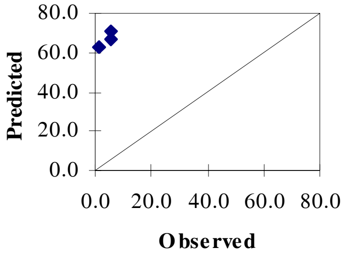
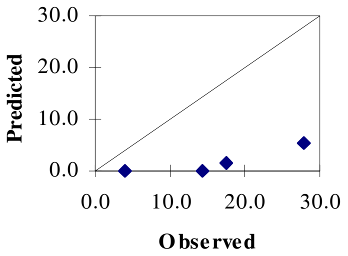
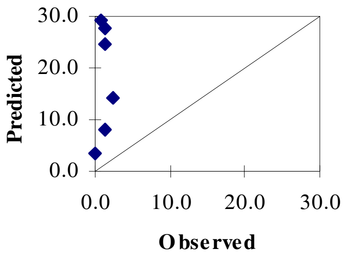
SHRP	Age	Alligator Cracking		Departure	Percent	Graph of	TESTING OF HYPOTHESES / REMARKS				
ID		Observed	Predicted	(obs-pre)	Departure	Observed Vs. Predicted Alligator Cracking	Null Hypothesis (H_0)	B_0=0	B_1=1	Null Hypothesis (H_0)	r=0
	years							(Intercept)	(Slope)		(corr.coef.)
1047	20.0	1.115	62.840	-61.724	-98.2	 80.0 60.0 40.0 20.0 0.0 Predicted 0.0 20.0 40.0 60.0 80.0 Observed	Regression Coeffs	61.163	1.503	Correlation coeff.(r)	0.874
	21.9	5.413	67.221	-61.808	-91.9		Standard Error	3.740	0.837	t-statistic	1.795
	24.1	5.413	71.376	-65.963	-92.4		t-statistic	16.355	0.601	Degress of freedom	1
							Degrees of freedom	1	1	p-value (Prob>| r |)	0.324
							p value (Prob>| t |)	0.039	0.656	Reject H_0?	Can't
							Upper 95%	108.681	12.141	**Remarks:**	
							Lower 95%	13.645	-9.136	o Inadequate data for analysis.	
							Reject H_0?	Reject	Can't	o Mean departure is too large.	
							Regression Statistics:			o Poor prediction.	
								R square =	0.7631		
		Mean =		-63.165	-94.2			Root MSE =	2.9381		
		Std. Deviation =		2.423	3.5			Observations =	3		
1050	5.4	4.015	0.021	3.994	18885.3	 30.0 20.0 10.0 0.0 Predicted 0.0 10.0 20.0 30.0 Observed	Regression Coeffs	-1.900	0.227	Correlation coeff.	0.890
	5.9	14.213	0.074	14.139	19236.9		Standard Error	1.475	0.082	t-statistic	2.768
	8.0	17.406	1.370	16.035	1170.2		t-statistic	-1.288	-9.437	Degrees of freedom	2
	10.1	27.837	5.328	22.509	422.5		Degrees of freedom	2	2	p-value (Prob>| r |)	0.110
							p value (Prob>| t |)	0.327	0.011	Reject H_0?	Can't
							Upper 95%	4.446	0.579	**Remarks:**	
							Lower 95%	-8.246	-0.126	o Inadequate data for analysis.	
							Reject H_0?	Can't	Reject	o Mean departure is large.	
							Regression Statistics:			o Trends don't match.	
								R square =	0.7930	o Fig D.18 suggests a steeper trend.	
		Mean =		14.169	9928.7			Root MSE =	1.3926		
		Std. Deviation =		7.672	10550.5			Observations =	4		
1060	5.1	0.000	3.367	-3.367	-100.0	 30.0 20.0 10.0 0.0 Predicted 0.0 10.0 20.0 30.0 Observed	Regression Coeffs	13	4.156	Correlation coeff.	0.292
	6.1	1.214	7.933	-6.719	-84.7		Standard Error	9.353	6.801	t-statistic	0.611
	7.1	2.297	14.194	-11.898	-83.8		t-statistic	1.374	0.464	Degrees of freedom	4
	8.6	1.411	24.593	-23.182	-94.3		Degrees of freedom	4	4	p-value (Prob>| r |)	0.574
							p-value (Prob>| t |)	0.241	0.667	Reject H_0?	Can't
	9.1	1.411	27.530	-26.119	-94.9		Upper 95%	38.819	23.038	**Remarks:**	
	9.3	0.787	29.080	-28.293	-97.3		Lower 95%	-13.116	-14.726	o Mean and std. deviation of	
							Reject H_0?	Can't	Can't	departure are large.	
							Regression Statistics:			o Very high standard error.	
								R square =	0.0854	o Trends don't match.	
		Mean =		-16.596	-92.5			Root MSE =	11.583	o Fig D.19 suggests a flatter trend.	
		Std. Deviation =		10.635	6.7			Observations =	6		

TABLE E.3 Analysis of TxDOT-PMIS Alligator Cracking Models (A+L)

SHRP ID	Age	Alligator Cracking Observed	Alligator Cracking Predicted	Departure (obs-pre)	Percent Departure	Graph of Observed Vs. Predicted Alligator Cracking
	years					
1047	20.0	1.115	62.840	-61.724	-98.2	
	21.9	5.413	67.221	-61.808	-91.9	
	24.1	5.413	71.376	-65.963	-92.4	
			Mean =	-63.165	-94.2	
			Std. Deviation =	2.423	3.5	
1050	5.4	4.015	0.021	3.994	18885.3	
	5.9	14.213	0.074	14.139	19236.9	
	8.0	17.406	1.370	16.035	1170.2	
	10.1	27.837	5.328	22.509	422.5	
			Mean =	14.169	9928.7	
			Std. Deviation =	7.672	10550.5	
1060	5.1	0.000	3.367	-3.367	-100.0	
	6.1	1.214	7.933	-6.719	-84.7	
	7.1	2.297	14.194	-11.898	-83.8	
	8.6	1.411	24.593	-23.182	-94.3	
	9.1	1.411	27.530	-26.119	-94.9	
	9.3	0.787	29.080	-28.293	-97.3	
			Mean =	-16.596	-92.5	
			Std. Deviation =	10.635	6.7	

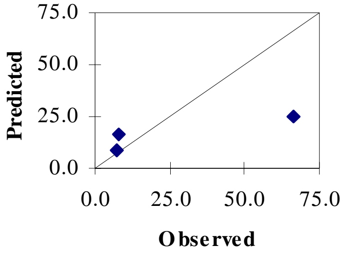
TESTING OF HYPOTHESES / REMARKS

SHRP ID	Null Hypothesis (H_0)	$B_0=0$ (Intercept)	$B_1=1$ (Slope)	Null Hypothesis (H_0)	r=0 (corr.coef.)
1047	Regression Coeffs	61.163	1.503	Correlation coeff.(r)	0.874
	Standard Error	3.740	0.837	t-statistic	1.795
	t-statistic	16.355	0.601	Degreess of freedom	1
	Degrees of freedom	1	1	p-value (Prob>| r |)	0.324
	p value (Prob>| t |)	0.039	0.656	Reject H_0?	Can't
	Upper 95%	108.681	12.141	**Remarks:**	
	Lower 95%	13.645	-9.136	o Inadequate data for analysis.	
	Reject H_0?	Reject	Can't	o Mean departure is too large.	
	Regression Statistics:			o Poor prediction.	
	R square =		0.7631		
	Root MSE =		2.9381		
	Observations =		3		
1050	Regression Coeffs	-1.900	0.227	Correlation coeff.	0.890
	Standard Error	1.475	0.082	t-statistic	2.768
	t-statistic	-1.288	-9.437	Degrees of freedom	2
	Degrees of freedom	2	2	p-value (Prob>| r |)	0.110
	p value (Prob>| t |)	0.327	0.011	Reject H_0?	Can't
	Upper 95%	4.446	0.579	**Remarks:**	
	Lower 95%	-8.246	-0.126	o Inadequate data for analysis.	
	Reject H_0?	Can't	Reject	o Mean departure is large.	
	Regression Statistics:			o Trends don't match.	
	R square =		0.7930	o Fig D.18 suggests a steeper trend.	
	Root MSE =		1.3926		
	Observations =		4		
1060	Regression Coeffs	13	4.156	Correlation coeff.	0.292
	Standard Error	9.353	6.801	t-statistic	0.611
	t-statistic	1.374	0.464	Degrees of freedom	4
	Degrees of freedom	4	4	p-value (Prob>| r |)	0.574
	p-value (Prob>| t |)	0.241	0.667	Reject H_0?	Can't
	Upper 95%	38.819	23.038	**Remarks:**	
	Lower 95%	-13.116	-14.726	o Mean and std. deviation of	
	Reject H_0?	Can't	Can't	departure are large.	
	Regression Statistics:			o Very high standard error.	
	R square =		0.0854	o Trends don't match.	
	Root MSE =		11.583	o Fig D.19 suggests a flatter trend.	
	Observations =		6		

TABLE E.3 Analysis of TxDOT-PMIS Alligator Cracking Models (A+L) (Continued)

SHRP ID	Age (years)	Alligator Cracking Observed	Alligator Cracking Predicted	Departure (obs-pre)	Percent Departure
1096	10.0	7.185	8.674	-1.489	-17.2
	12.0	7.972	16.689	-8.717	-52.2
	14.0	66.503	25.041	41.462	165.6
			Mean =	10.419	32.1
			Std. Deviation =	27.126	117.0

Graph of Observed Vs. Predicted Alligator Cracking

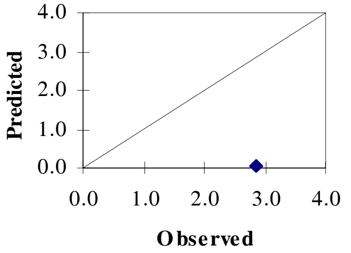


TESTING OF HYPOTHESES / REMARKS

Null Hypothesis (H_0)	B_0=0 (Intercept)	B_1=1 (Slope)	Null Hypothesis (H_0)	r=0 (corr.coef.)
Regression Coeffs	11.056	0.211	Correlation coeff.	0.878
Standard Error	4.486	0.115	t-statistic	1.830
t-statistic	2.464	-6.839	Degrees of freedom	1
Degrees of freedom	1	1	p-value (Prob>| r |)	0.318
p-value (Prob>| t |)	0.245	0.092	Reject H_0?	Can't
Upper 95%	68.060	1.677		
Lower 95%	-45.949	-1.255		
Reject H_0?	Can't	Can't		
Regression Statistics:				
R square =		0.7700		
Root MSE =		5.5502		
Observations =		3		

Remarks:
- o Inadequate data for analysis.
- o Mean and std. deviation of departure are large.
- o Trends don't match.
- o Fig D.23 suggests a steeper trend.

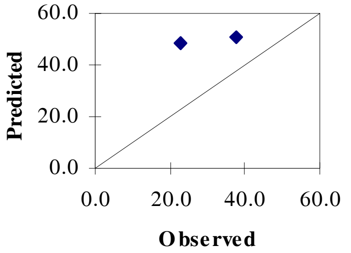
SHRP ID	Age (years)	Alligator Cracking Observed	Alligator Cracking Predicted	Departure (obs-pre)	Percent Departure
1113	6.4	2.849	0.064	2.786	4386.2
			Mean =	2.786	4386.2
			Std. Deviation =	-	-



Null Hypothesis (H_0)	B_0=0 (Intercept)	B_1=1 (Slope)	Null Hypothesis (H_0)	r=0 (corr.coef.)
Regression Coeffs			Correlation coeff.	
Standard Error			t-statistic	
t-statistic			Degrees of freedom	
Degrees of freedom			p-value (Prob>| r |)	
p-value (Prob>| t |)				
Upper 95%				
Lower 95%				
Regression Statistics:				
R square =				
Root MSE =				
Observations =		1		

Remarks:
- o Hypothesis testing is not possible due to lack of data.
- o Pretty close prediction.

SHRP ID	Age (years)	Alligator Cracking Observed	Alligator Cracking Predicted	Departure (obs-pre)	Percent Departure
1130	18.7	22.921	48.118	-25.197	-52.4
	19.6	37.830	51.144	-13.314	-26.0
			Mean =	-19.256	-39.2
			Std. Deviation =	8.402	18.6



Null Hypothesis (H_0)	B_0=0 (Intercept)	B_1=1 (Slope)	Null Hypothesis (H_0)	r=0 (corr.coef.)
Regression Coeffs			Correlation coeff.	
Standard Error			t-statistic	
t-statistic			Degrees of freedom	
Degrees of freedom			p-value (Prob>| r |)	
p-value (Prob>| t |)				
Upper 95%				
Lower 95%				
Regression Statistics:				
R square =				
Root MSE =				
Observations =		2		

Remarks:
- o Hypothesis testing is not possible due to lack of data.
- o Mean departure is large.
- o Trends don't match.
- o Fig D.25 suggests a steeper trend.

TABLE E.3 Analysis of TxDOT-PMIS Alligator Cracking Models (A+L) (Continued)

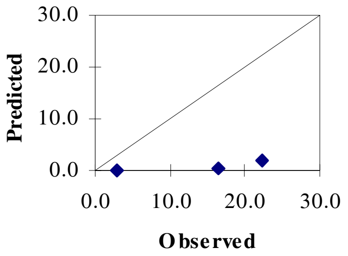
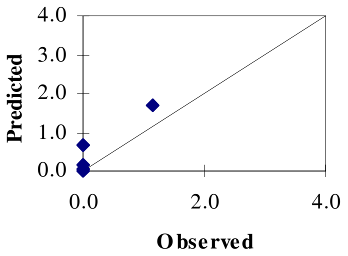
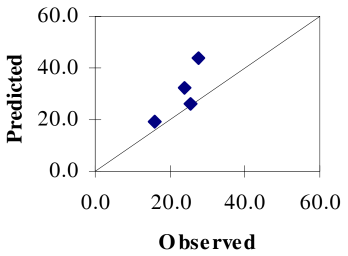
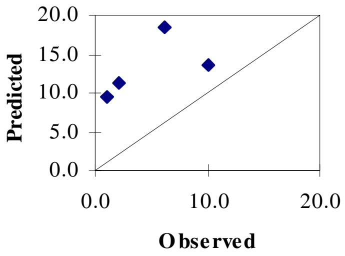
SHRP	Age	Alligator Cracking		Departure	Percent	Graph of	TESTING OF HYPOTHESES / REMARKS				
ID		Observed	Predicted	(obs-pre)	Departure	Observed Vs. Predicted Alligator Cracking	Null Hypothesis (H_0)	B_0=0	B_1=1	Null Hypothesis (H_0)	r=0
	years							(Intercept)	(Slope)		(corr.coef.)
1168	5.8	2.989	0.006	2.983	49935.8		Regression Coeffs	-0.444	0.085	Correlation coeff.	0.836
	8.0	16.373	0.325	16.048	4942.5		Standard Error	0.903	0.056	t-statistic	1.522
	9.9	22.393	1.899	20.494	1079.3		t-statistic	-0.491	-16.32	Degrees of freedom	1
							Degrees of freedom	1	1	p-value (Prob>| r |)	0.370
							p-value (Prob>| t |)	0.709	0.039	Reject H_0?	Can't
							Upper 95%	11.026	0.797	**Remarks:** o Analysis is inappropriate due to inadequate data. o Mean departure is large. o Trends don't match. o Fig D.26 suggests a steeper trend.	
							Lower 95%	-11.91	-0.627		
							Reject H_0?	Can't	Reject		
							Regression Statistics:				
								R square =	0.6984		
		Mean =		13.175	18652.5			Root MSE =	0.7871		
		Std. Deviation =		9.102	27160.9			Observations =	3		
3579	3.6	0.000	0.000	0.000	-100.0		Regression Coeffs	0.214	1.317	Correlation coeff.	0.922
	5.1	0.000	0.031	-0.031	-100.0		Standard Error	0.162	0.318	t-statistic	4.139
	5.8	0.000	0.132	-0.132	-100.0		t-statistic	1.321	0.997	Degrees of freedom	3
	6.9	0.000	0.691	-0.691	-100.0		Degrees of freedom	3	3	p-value (Prob>| r |)	0.026
	7.7	1.136	1.710	-0.574	-33.6		p-value (Prob>| t |)	0.278	0.392	Reject H_0?	Reject
							Upper 95%	0.728	2.330	**Remarks:** o Analysis is inappropriate due to inadequate data. o Pretty close prediction. o Good correlation.	
							Lower 95%	-0.301	0.304		
							Reject H_0?	Can't	Can't		
							Regression Statistics:				
								R square =	0.8509		
		Mean =		-0.286	-86.7			Root MSE =	0.3235		
		Std. Deviation =		0.323	29.7			Observations =	5		
3729	7.9	15.912	19.415	-3.503	-18.0		Regression Coeffs	-8.252	1.667	Correlation coeff.	0.814
	8.8	25.492	25.830	-0.338	-1.3		Standard Error	19.871	0.841	t-statistic	1.981
	9.8	23.772	32.556	-8.784	-27.0		t-statistic	-0.415	0.793	Degrees of freedom	2
	11.8	27.614	43.883	-16.269	-37.1		Degrees of freedom	2	2	p-value (Prob>| r |)	0.186
							p-value (Prob>| t |)	0.718	0.511	Reject H_0?	Can't
							Upper 95%	77.246	5.288	**Remarks:** o Analysis is inappropriate due to inadequate data. o Fair prediction. o Trends don't match. o Fig D.29 suggests a flatter trend.	
							Lower 95%	-93.75	-1.953		
							Reject H_0?	Can't	Can't		
							Regression Statistics:				
								R square =	0.6625		
		Mean =		-7.223	-20.9			Root MSE =	7.4401		
		Std. Deviation =		6.964	15.2			Observations =	4		

TABLE E.3 Analysis of TxDOT-PMIS Alligator Cracking Models (A+L) (Continued)

SHRP ID	Age (years)	Alligator Cracking Observed	Alligator Cracking Predicted	Departure (obs-pre)	Percent Departure
3739	8.9	0.984	9.464	-8.480	-89.6
	9.3	2.205	11.159	-8.954	-80.2
	9.9	10.114	13.662	-3.549	-26.0
	10.9	6.151	18.585	-12.434	-66.9
			Mean =	-8.354	-65.7
			Std. Deviation =	3.657	28.1

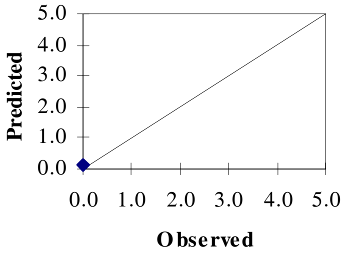
Graph of Observed Vs. Predicted Alligator Cracking



Null Hypothesis (H_0)	$B_0=0$ (Intercept)	$B_1=1$ (Slope)	Null Hypothesis (H_0)	r=0 (corr.coef.)
Regression Coeffs	10.444	0.570	Correlation coeff.	0.594
Standard Error	3.299	0.546	t-statistic	1.044
t-statistic	3.165	-0.787	Degrees of freedom	2
Degrees of freedom	2	2	p-value (Prob>| r |)	0.406
p-value (Prob>| t |)	0.087	0.514	Reject H_0?	Can't
Upper 95%	24.640	2.921		
Lower 95%	-3.753	-1.780		
Reject H_0?	Can't	Can't		
Regression Statistics:				
	R square =	0.3528		
	Root MSE =	3.9136		
	Observations =	4		

Remarks:
- o Analysis is inappropriate due to inadequate data.
- o Large standard error.
- o Fair prediction.

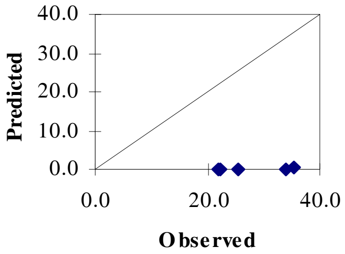
SHRP ID	Age (years)	Alligator Cracking Observed	Alligator Cracking Predicted	Departure (obs-pre)	Percent Departure
3875	5.6	0.000	0.107	-0.107	-100.0
			Mean =	-0.107	-100.0
			Std. Deviation =	-	-



Null Hypothesis (H_0)	$B_0=0$ (Intercept)	$B_1=1$ (Slope)	Null Hypothesis (H_0)	r=0 (corr.coef.)
Regression Coeffs			Correlation coeff.	
Standard Error			t-statistic	
t-statistic			Degrees of freedom	
Degrees of freedom			p-value (Prob>| r |)	
p-value (Prob>| t |)			Reject H_0?	
Upper 95%				
Lower 95%				
Reject H_0?				
Regression Statistics:				
	R square =			
	Root MSE =			
	Observations =	1		

Remarks:
- o Hypothesis testing is not possible due to lack of data.
- o Pretty close prediction.
- o Large percent difference.

SHRP ID	Age (years)	Alligator Cracking Observed	Alligator Cracking Predicted	Departure (obs-pre)	Percent Departure
9005	4.1	21.947	0.000	21.947	*288429.1*
	4.6	22.267	0.000	22.267	*288429.1*
	5.0	25.332	0.000	25.332	*288429.1*
	9.5	33.967	0.171	33.796	19750.4
	9.9	35.440	0.262	35.178	13443.1
			Mean =	27.704	179696.2
			Std. Deviation =	6.350	148905.4



Null Hypothesis (H_0)	$B_0=0$ (Intercept)	$B_1=1$ (Slope)	Null Hypothesis (H_0)	r=0 (corr.coef.)
Regression Coeffs	-0.421	0.018	Correlation coeff.	0.963
Standard Error	0.084	0.003	t-statistic	6.174
t-statistic	-5.014	-331.7	Degrees of freedom	3
Degrees of freedom	3	3	p-value (Prob>| r |)	0.009
p-value (Prob>| t |)	0.015	0.000	Reject H_0?	Reject
Upper 95%	-0.154	0.028		
Lower 95%	-0.689	0.009		
Reject H_0?	Reject	Reject		
Regression Statistics:				
	R square =	0.9270		
	Root MSE =	0.0383		
	Observations =	5		

Remarks:
- o Analysis is inappropriate due to inadequate data.
- o Fair correlation.
- o Mean departure is large.
- o Trends don't match.
- o Fig D.32 suggests a steeper trend.