DEVELOPMENT AND IMPLEMENTATION OF ARIZONA DEPARTMENT OF TRANSPORTATION (ADOT) PAVEMENT MANAGEMENT SYSTEM (PMS)

Final Report 494

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April 2006

Prepared for:
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in cooperation with
the U.S. Department of Transportation
Federal Highway Administration

DISCLAIMER

Technical Report Documentation Page

1. Report No. FHWA-AZ-06-494	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DEVELOPMENT AND IMPLEMENTATION OF ARIZONA DEPARTMENT OF TRANSPORTATION (ADOT) PAVEMENT MANAGEMENT SYSTEM (PMS)		5. Report Date April 2006 6. Performing Organization Code
7. Author Sameh Zaghloul, Ph.D., Khaled Helali, Ph.D., Wael Bekheet, Ph.D.		8. Performing Organization Report No.
9. Performing Organization Name and Address Stantec Consulting Inc. 49 Frederick Street Kitchener, ON N2H 6M7 8211 S, 48th Street Phoenix, AZ 85044		10. Work Unit No. 11. Contract or Grant No. SPR-PL-1(57)-494
12. Sponsoring Agency Name and Address Arizona Department of Transportation 206 S. 17th Avenue Phoenix, Arizona 85007 Project Manager: Yongqi Li		13. Type of Report & Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration		

16. Abstract

Arizona Department of Transportation (ADOT) has been one of the pioneering states in the development and implementation of Pavement Management Systems (PMS). Since the early 1980's, ADOT has been using pavement management tools to manage, maintain and preserve Arizona's highway network. ADOT's PMS tools were originally based on a probabilistic approach for modeling the pavement performance, which were adequate for the original ADOT requirements.

Recently, ADOT has decided to expand the use of the PMS tools to also support the pavement maintenance operations. This required a change in the existing ADOT's PMS tools, which prompted a need to move to a different pavement management software. Subsequently, ADOT selected Stantec's Highway Pavement Management Application (HPMA) software to replace its pavement management system, and retained Stantec's services for structuring, data loading, model development, and implementing the HPMA.

HPMA is a single software application that provides full database management and analysis capabilities required by the two types of users (PMS and Maintenance). The HPMA provides capability for users to work at both the detailed highway level and the aggregated section level. Also it provides a wide variety of analysis capabilities, including corrective maintenance, preventive maintenance, and rehabilitation analysis.

This report documents the approach used to achieve the goals of this project including the customization of the HPMA to address ADOT requirements, the development of the analysis models, which are based on ADOT historic performance data, and the implementation of these analysis models in conducting a statewide analysis.

17. Key Words		18. Distribution Statement		23. Registrant's Seal
PMS, Rehabilitation, Preventive Maintenance, Corrective Maintenance, Prediction Models, Decision Trees		Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia, 22161		
19. Security Classification Unclassified	20. Security Classification Unclassified	21. No. of Pages 219	22. Price	

SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	Inches	25.4	millimeters	mm
ft	Feet	0.305	meters	m
yd	Yards	0.914	meters	m
mi	Miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	Acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	Gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.			
		MASS		
oz	Ounces	28.35	grams	g
lb	Pounds	0.454	kilograms	kg
T	short tons (2000lb)	0.907	megagrams (or “metric ton”)	mg (or “t”)
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE AND PRESSURE OR STRESS		
lbf	Poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	Square millimeters	0.0016	square inches	in^2
m^2	Square meters	10.764	square feet	ft^2
m^2	Square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	Cubic meters	35.315	cubic feet	ft^3
m^3	Cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (or “metric ton”)	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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EXECUTIVE SUMMARY

Since the early 1980's, ADOT has been using pavement management tools to manage, maintain and preserve Arizona's highway network. ADOT's PMS tools were originally based on a probabilistic approach for modeling the pavement performance, which were adequate for the original ADOT requirements. Recently, ADOT has decided to expand the use of the PMS tools to also support the pavement maintenance operations and project level pavement rehabilitation activities. This required a change in the existing ADOT's PMS tools, which prompted a need to move to a different pavement management software. Subsequently, ADOT selected Stantec's Highway Pavement Management Application (HPMA) software to replace its pavement management system, and retained Stantec's services for structuring, data loading, model development, and implementing the HPMA.

The overall approach followed to achieve the project objectives is divided into four main phases, which are:

1. Development of a Conceptual Design and Layout
2. Structure and Develop Pavement Management Database and Models
3. Conduct State-wide Analysis
4. Install HPMA, train ADOT staff, and provide software technical support

The development of the conceptual plan involved assessing the old ADOT database structure and data elements, identifying the needs of the various system users and determining the availability, relevance and method of importing the data items. The types of the available data were reviewed in terms of the sources, reliability, and level of necessity. This task also involved reviewing the models and parameters used in the Department’s current pavement management system. Based on this review, a detailed conceptual plan for the development of ADOT HPMA was developed.

The second phase of the project was directed towards loading ADOT's data into the HPMA database, modifying some of the HPMA functions and adding more functions to meet ADOT requests, and developing the required analysis models. Data loading and model development were carried out based on the conceptual plan developed in Phase 1 of the project and the feedback received from the Technical Advisory Committee. Data was loaded from the existing data sources in ADOT and converted as necessary. The HPMA code tables were first populated and then the data was loaded as required. ADOT requested a number of modifications and enhancements to the functionality of the HPMA software, which were implemented in this phase of the project. These modifications included the inclusion of the maintenance history in the priority rating, modifications to some of the table structures, adding some additional reports and others. The HPMA models and parameters including the condition indices, pavement types, distress types, rehabilitation and maintenance treatments, and decision trees, were developed at this stage.

The completed ADOT HPMA is a single software application that provides full database management and analysis capabilities required by the two types of users (PMS and Maintenance). The HPMA provides capability for users to work at both the detailed highway level and the aggregated section level. Also it provides a wide variety of analysis capabilities, including corrective maintenance, preventive maintenance, and rehabilitation analysis.

When the ADOT HPMA was completed, a statewide analysis to demonstrate the analysis modules in the system was carried out using historic ADOT data. The analysis included identifying ADOT's network budgetary needs and network performance using historic data and comparing these results to actual measured performance data. The results of the analysis showed that ADOT HPMA successfully modeled the historic trends of ADOT pavements and accurately represented ADOT's network conditions.

To demonstrate ADOT HPMA software performance and verify the analysis settings and models in the software, two sets of analyses were performed using the ADOT HPMA. The analyses were performed starting from the year 2000. Thus, the performance data from the following years were not considered in the analysis. The analysis results were subsequently evaluated against the actual data from the years 2000 through 2003.

The objective of the first analysis set was to predict the funding levels for the network required to achieve specific performance levels over the years 2000 through 2003. These performance levels were the actual measured performance of ADOT during this period. The analysis results were then compared to the actual funding levels provided by ADOT during the same analysis period.

The objective of the second analysis was to predict the network performance under a specific budget stream over the years 2000 through 2003. Again, this budget represented the actual budget spent over the analysis period, and the analysis results were compared to the actual network performance over the same period.

1.0 INTRODUCTION

1.1 BACKGROUND

Arizona Department of Transportation (ADOT) has been one of the pioneering states in the development and implementation of Pavement Management Systems (PMS). Since the early 1980's, ADOT has been using pavement management tools to manage, maintain and preserve Arizona's highway network. ADOT's PMS tools were originally based on a probabilistic approach for modeling the pavement performance, which were adequate for the original ADOT requirements.

Recently, ADOT has decided to expand the use of the PMS tools to also support the pavement maintenance operations. This required a change in the existing ADOT's PMS tools, which prompted a need to move to a different pavement management software. Subsequently, ADOT selected Stantec's Highway Pavement Management Application (HPMA) software to replace its pavement management system, and retained Stantec's services for structuring, data loading, model development, and implementing the HPMA.

HPMA is a single software application that provides full database management and analysis capabilities required by the two types of users (PMS and Maintenance). The HPMA provides capability for users to work at both the detailed highway level and the aggregated section level. Also it provides a wide variety of analysis capabilities, including corrective maintenance, preventive maintenance, and rehabilitation analysis.

This report documents the approach used to achieve the goals of this project including the customization of the HPMA to address ADOT requirements, the development of the analysis models, which are based on ADOT historic performance data, and the implementation of these analysis models in conducting a statewide analysis.

1.2 REPORT ORGANIZATION

The report is divided into seven sections. Sections 1 and 2 provide an introduction and overview of the project approach and the HPMA software, respectively. Section 3 details the HPMA customization to address ADOT requirements, while Section 4 gives an overview of the data loading process.

Section 5 of the report describes the development of the analysis models required for the Maintenance and Rehabilitation (M&R) analysis. Results of the statewide optimization analysis are presented in Section 6, while in Section 7 the installation of the HPMA on ADOT computers is described.

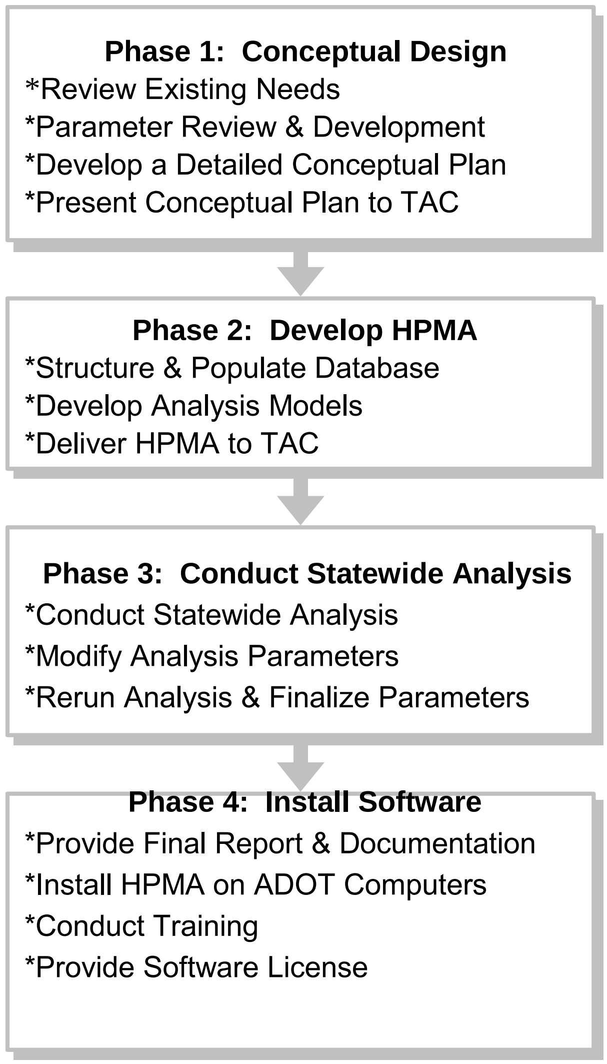

Figure 2.1: Project Outline

2.0 PROJECT APPROACH OVERVIEW

In an effort to expand its use of the pavement management tools to support maintenance functions, ADOT selected Stantec's Highway Pavement Management Application (HPMA) software to replace its pavement management system, and retained Stantec's services for structuring, data loading, model development, and implementing the HPMA.

The HPMA is a single software application that provides complete database management and analysis capabilities. It provides capability for users to work at both the detailed highway level and the aggregated section level. Also it provides a wide variety of analysis capabilities, including corrective maintenance, preventive maintenance, and rehabilitation analysis.

In this section, an overview of the project approach together with the HPMA is presented.

2.1 PROJECT APPROACH OVERVIEW

Figure 2.1 shows the overall approach followed to achieve the project objectives. The approach is divided into four main phases, which are:

1. Development of a Conceptual Design and Layout
2. Structure and Develop Pavement Management Database and Models
3. Conduct State-wide Analysis
4. Install HPMA, train ADOT staff, and provide software technical support

The development of the conceptual plan involved assessing the old ADOT database structure and data elements, identifying the needs of the various system users and determining the availability, relevance and method of importing the data items. The types of the available data were reviewed in terms of the sources, reliability, and level of necessity. This task also involved reviewing the models and parameters used in the Department’s current pavement management system. Based on this review, a detailed conceptual plan for the development of ADOT HPMA was developed and presented to the Technical Advisory Committee (TAC).

As part of Phase 1 of the project, Stantec provided a three-day training session in Phoenix for different expected users of ADOT's HPMA. The main objective of this training was to help ADOT staff understand the HPMA and thus better define the required software customization.

The second phase of the project was directed towards loading ADOT's data into the HPMA database, modifying some of the HPMA functions and adding more functions to satisfy ADOT requests, and developing the required analysis models. Data loading and model development were carried out based on the conceptual plan developed in Phase 1 of the project and the feedback received from TAC. Data was loaded from the existing data sources in ADOT and converted as necessary. The HPMA code tables were first populated and then the data was loaded as required.

ADOT requested a number of modifications and enhancements to the functionality of the HPMA software, which were implemented in this phase of the project. These modifications included the inclusion of the maintenance history in the priority rating, modifications to some of the table structures, and adding some additional reports, etc. Details of these modifications and enhancements are described in Section 3.0 of this report.

The HPMA models and parameters including the condition indices, pavement types, distress types, rehabilitation and maintenance treatments, decision trees, etc., were developed at this stage. The HPMA database and analysis models were then presented to the TAC for feedback.

In Phase 3 of the project, a statewide network analysis was performed. The main purpose of this analysis was to evaluate the loaded data and the developed models, as well as to fine tune the models to produce acceptable results. Maintenance and Rehabilitation (M&R) analysis, and a budget optimization analysis were conducted to produce a 5-year capital improvement program. Also, ADOT carried out Beta testing of the system and the analysis results, including a comparison with the existing pavement management system results. Based on the analysis results and results of the Beta testing, the models and analysis parameters were refined. The network analysis was then repeated and the results were highly correlated with the observed network performance and budgetary needs. The analysis results were deemed acceptable by ADOT.

The final Phase of the project involved the implementation and delivery of the HPMA to ADOT, where the system was installed at ADOT offices on a Microsoft® SQL server. Also this task involved the submission of the final report, user documentation, and training.

2.2 OVERVIEW OF HPMA SOFTWARE

The ADOT HPMA includes four subsystems namely: the Database Subsystem, the Network Analysis Subsystem, the Engineering Feedback Subsystem, and the Project Design and Analysis Subsystem.

2.2.1 Database Management Subsystem

The HPMA database utilizes a two level structure to serve the required pavement management functions, which are a detailed highway database and a summarized sectional database.

All data types are loaded to the detailed highway database, as well as including all historical records. All detailed highway data items are referenced by physical location using the existing route identifier and milepost reference system defined within ADOT HPMA. The types of detailed data maintained in the database include:

- Inventory Data: section identification data (location, pavement type, functional class, etc.) and geometric data (length, width, number of lanes, etc.);

- Traffic Data: annual average daily traffic (AADT), equivalent single-axle load (ESAL), growth rates, etc.;
- Pavement Structure History Data: structural activity derived from the AS-BUILT Database and updated as rehabilitation treatments are implemented;
- Maintenance History Data: activities and costs by location to come from the maintenance management system (MMS); and
- Performance data from the condition data collection (field testing) efforts. The primary PMS performance data for the network analysis are the surface distress, roughness and rut data.

The main purpose of building the section data view is to create homogeneous sections from the detailed database for use in the M&R analysis and optimization. The creation of Sectional Data View (SDV) requires the detailed database to be loaded, the default prediction models to be populated and the parameter and code tables to be completed. The section data view creation module builds the SDVs from the section definitions and aggregates the appropriate data from the detailed highway database. Numeric fields are calculated as an average, weighted by the length of the sub-sections, while type fields are based on the longest length of sub-sections. The section data views are created within the system through the use of dynamic sectioning utilizing user-defined sectioning parameters, or as overrides, where the user defines the section limits to be included. It should be noted that there is no limit on the number of SDVs that can be created within ADOT HPMA, since any SDV is created based on the detailed highway level data already stored in the HPMA

Figure 2.2 shows the interactions of the HPMA subsystems. As can be seen, the Network Analysis Subsystem uses the sectional database; and the Engineering Feedback Subsystem and the Project Analysis Subsystem use the (highway) database.

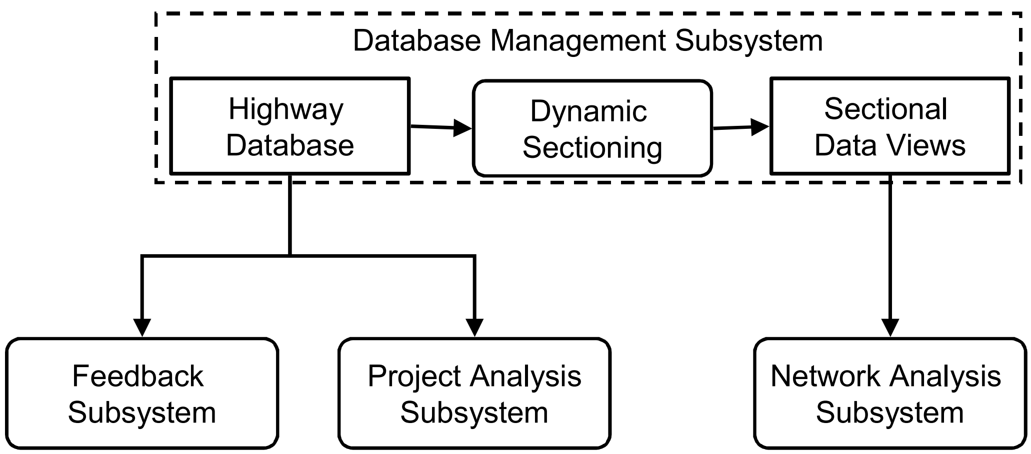

Figure 2.2: Relationship between ADOT HPMA Subsystems

The HPMA database subsystem provides several key functions. These functions include specific tools for performing the basic database management capabilities such as storage and update of highway attributes, browse, and edit functions. Also, functions to perform queries and calculate summary statistics are available in the subsystem.

Another major database management function is the access control. User access is controlled through the User Identification (ID) and password, which provides different levels of access. For example, limited number of users have access to the condition data update, while all users have access to view and report this data. As another example, users in one region will have access only to the data of their region.

2.2.2 Network Analysis Subsystem

The purpose of the network level analysis procedures is to determine the current and future maintenance and rehabilitation needs and to develop priority programs to implement the appropriate treatments. The Network Analysis Subsystem provides two types of analysis procedures, namely: the "Maintenance Analysis" and the "Maintenance and Rehabilitation Analysis", or "M&R Analysis". The "Maintenance Analysis" procedure provides a one-year program of maintenance activities based on the detailed analysis of distresses. The "M&R Analysis" procedure, on the other hand, provides multi-year work programs that can incorporate both maintenance and rehabilitation activities.

2.2.2.1 Maintenance Analysis Procedure

Two types of maintenance analysis are available in ADOT HPMA, which are:

- Maintenance Needs Analysis
- Maintenance Budget Analysis

The maintenance needs analysis uses the detailed surface distress data to estimate the demand-based maintenance needs for contract estimation purposes. This is based on maintenance standards that define the activities required in the next two years to fix the observed surface deficiencies. The observed distress data is compared to the maintenance standards to determine the actual requirements.

The maintenance budget analysis uses the output of the maintenance needs analysis and user defined budget constraints to generate a maintenance work program. In this program, sections and the recommended treatments are selected based on the highest cost-effectiveness. Effectiveness is expressed as a function of the improvement in the surface distress index that should be observed after fixing the distress.

2.2.2.2 Maintenance & Rehabilitation Analysis Procedure

The Rehabilitation Programming Subsystem provides the following capabilities:

- Rehabilitation needs analysis
- Rehabilitation alternatives analysis
- Rehabilitation programming and budgeting analysis

The rehabilitation needs analysis is used to predict section performance in terms of the individual performance indices and to determine the present and future rehabilitation needs. The rehabilitation alternatives analysis involves the strategy screening, performance predictions, and economic analyses of the rehabilitation alternatives.

The rehabilitation programming and budgeting analysis provides two main functions, which are developing rehabilitation work programs based on budget constraints and determining the effects of various funding levels on the network performance and needs backlog (or conversely, determining the required budget levels to provide given levels of service).

The optimization analysis includes two modes of operation:

- Effectiveness-maximization, where the optimal work programs are determined based on given funding levels
- Cost-minimization, which provides a means of determining required funding levels to achieve specific performance levels

Funding scenarios can be evaluated by running the analysis in the effectiveness maximization mode with the different funding levels as input constraints. Service level scenarios can be evaluated by running the analysis in the cost-minimization mode with the service levels as input constraints in terms of required performance.

2.2.3 Engineering Feedback Subsystem

The Engineering Feedback Subsystem provides information feedback for evaluating the effectiveness of achieving technical goals, and includes the following capabilities:

- Analysis of pavement performance trends providing feedback for updating the performance prediction models
- Evaluation of the effectiveness of specific maintenance and rehabilitation alternatives in achieving technical goals such as minimum expected life, extension of service life, reduction in rutting, etc.
- Determination of distress trends

Within this subsystem, the maintenance and rehabilitation treatment effectiveness analysis provides the capability to evaluate the effectiveness of specific activities in terms of performance and cost for a specific group of sections. A specific group of sections for this analysis can be defined in terms of a pavement performance class, highway, functional class, etc. The types of activities to be analyzed can include original construction or any defined maintenance or rehabilitation activity. This feature allows ADOT to determine which treatment alternatives are meeting the expected performance goals in terms of distresses, roughness and overall service life.

The performance model analysis component of the Engineering Feedback Subsystem examines the historical records for sections matching each performance class and provides plots of the actual section performance data along with the predictions of the current models. Statistical calculations are performed to determine updated model coefficients based on the actual data set. The updated coefficients can then be used to fine-tune the prediction models.

The distress trend analysis component of the Engineering Feedback Subsystem can be used to provide feedback on the progression of observed distresses. The analysis involves selecting all of the distress data for a network subset and performing statistical analyses to determine average distress trends for each distress type. The results are summary statistics including number of observations, averages, standard deviations, etc. and plots to show the observed distresses and the average percentage of the distressed area with age for each distress type. By selecting the implementation of particular maintenance or rehabilitation treatments as part of the subset definition, this capability can identify any trends in distress occurrence for specific treatments.

2.2.4 Project Design & Analysis Subsystem

The Project Design & Analysis Subsystem provides a means of performing project-level Life Cycle Cost Analysis (LCCA).

Typically, detailed design alternatives for selected projects are evaluated based on life cycle costs and effectiveness. Results of FWD analysis along with surface distress, rutting and roughness data, are used in this evaluation. The user has the option of selecting the alternative design with highest cost-effectiveness, the lowest life cycle cost or the lowest user delay.

3.0 ADOT PMS FUNCTIONALITY AND SOFTWARE MODIFICATION

ADOT required a comprehensive set of functions in the HPMA covering all aspects of pavement management, including performance predictions, analysis of rehabilitation alternatives, and network optimization. Most of these needs were originally available in the HPMA software. However, during the course of the project, additional functionality based on ADOT requirements were identified and added to the software. The customization of the software included enhancing some of the existing functions and adding new functions that allows users to perform specific data manipulation and analysis tasks.

In this section, the specific functional modifications to the HPMA added as per ADOT requirements are presented. Table 3.1 shows a summary of these modifications, with reference to the subsection number where these modifications are described. The function number refers to the screen number in the ADOT HPMA. It should be noted that this Section does not cover all the functions of the HPMA, but only highlights the functions that were added to satisfy ADOT requests.

Table 3.1: PMS Needs and HPMA Function

Need	HPMA Function	Software Modification
Highway referencing	Function 2-1 provides a variety of referencing methods.	Function 2-1 was modified to include ADOT required referencing system. Details in Section 3.1
Multiple treatment occurrences within the same year	HPMA originally used the "year" as a reference key	HPMA was modified to account for multiple occurrences within the same year. Details in Section 3.2
Overall Index including maintenance costs	The HPMA provides several performance indices to be included in the overall index and the priority rating	HPMA Function 3-1 was modified to include the maintenance costs in the Overall index and Priority rating. Details in Section 3.3
Performance prediction models for roughness and distresses	Functions 3-3 and 3-4 are used to define models by performance class. Function 5-1 builds site-specific models for each section Functions 7-1 and 7-2 are used to analyze the historical database to update performance class based models The individual section models could not be modified	Minor modifications were required for the existing HPMA functionality Details in Section 3.4

Need	HPMA Function	Software Modification
FWD analysis calculations using Structural Overlay Design for Arizona (SODA)	Functions 1-2-1 and 4-1-14 provide FWD calculations using AASHTO models. The SODA required software modifications	Minor modifications to Function 4-1-14 Details in Section 3.5
Summary network performance plot including IRI	Function 4-4 provides summary network performance plots.	Function 4-4 was modified to include IRI. Details in Section 3.6
Construction history data including the percent voids	Function 4-1-17 provides construction history details, however ADOT has identified additional information to be stored	Function 4-1-17 was modified. Details in Section 3.7
Report summarizing historical maintenance activities including costs and level of service	Function 5-5 provides various sections reporting capabilities	Function 5-5 was modified to provide the required ADOT format. Details in Section 3.8
District and Maintenance Organization numbers using maintenance codes	HPMA jurisdiction fields used to store District and Maintenance Organization numbers	The jurisdiction field was modified to store the correct number of digits Details in Section 3.9
Optimization performance and cost summary graphic reports	Function 6-3-r provides optimization reporting including various graphic reports. Performance graphs are available but cost summary was only produced as a text summary	Graphic cost summary report was added in Function 6-3-r Details in Section 3.10
Friction history data including additional items	Function 4-1-15 provides friction history data, however ADOT identified additional information to be stored	Function 4-1-15 was enhanced. Details in Section 3.11
Network performance plots by route type	Functions 4-4 and 5-7 provide summary network performance plots, but the plots could not be categorized by route type	The software was modified to provide network performance plots by route type. Details in Section 3.12.
Optimization performance constraints by route type	Function 6-3-c allows the users to define budget and performance constraints for different indices. ADOT needed to be able to define performance constraints by route type	Function 6-3-c was changed to allow constraints by route type Details in Section 3.13.
Import of PECOS maintenance activity data to highway database	A custom external load module was developed to transfer data from a PECOS file to the HPMA database	One-time development

3.1 HIGHWAY REFERENCING BASED ON MILEPOST RELATIVE DISTANCE

The HPMA highway database uses a Linear Referencing system. This referencing system originally included two referencing methods: a true-distance referencing method and a reference post plus an offset referencing method, as shown in Figure 3.1

ADOT highways are referenced in the HPMA based on milepost relative distances, such that the reference post is considered as an approximate distance. However, the true milepost location is stored as true distance in the landmark table. Other landmarks such as bridges and highway intersections are stored based on milepost relative distances in the same table.

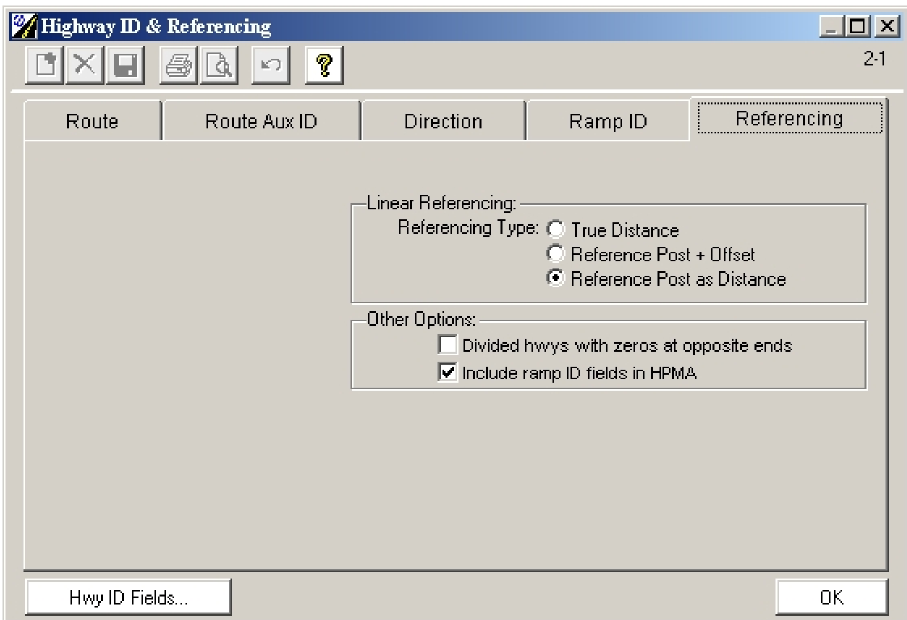

Figure 3.1: Highway Referencing

In order to calculate true section lengths when building section data views, the milepost locations, which are stored in the landmark table, are used in reference to the nominal mileposts stored in the highway definition table. Therefore, a new setting was required on the referencing tab of function 2-1 to indicate this setting, as shown in Figure 3.1. The section data view builder (function 5-1) was modified to use this setting to calculate correct section lengths from the milepost locations.

3.2 CONDITION DATA WITH MULTIPLE OCCURRENCES PER YEAR

Previously the HPMA highway database historical tables used location and year as a key field, which allowed only one condition measurement per year. However, ADOT's historic condition data includes in some cases multiple measurements for a specific section in the same year. Therefore, a change was done to this key to allow multiple entries in the same year for the pavement structure, deflection, and friction tables.

3.3 OVERALL INDEX INCLUDING MAINTENANCE COSTS

The HPMA provides several performance indices including an overall index, which combines the roughness, distress and deflection based indices into an overall score. A priority index is also used to allow weighting of the overall index by other factors. ADOT indicated a need to include the average maintenance cost of the last three years in the overall index.

Neither the overall index nor the priority index is stored at the highway database level, although the overall index is calculated for use in certain highway database based graphs. Both the overall index and the priority index are calculated and stored with section data views. The priority index calculation method was modified to allow the inclusion of the past average maintenance costs, as shown in Figure 3.2. Also, the average maintenance cost was added as a new field to the section data view.

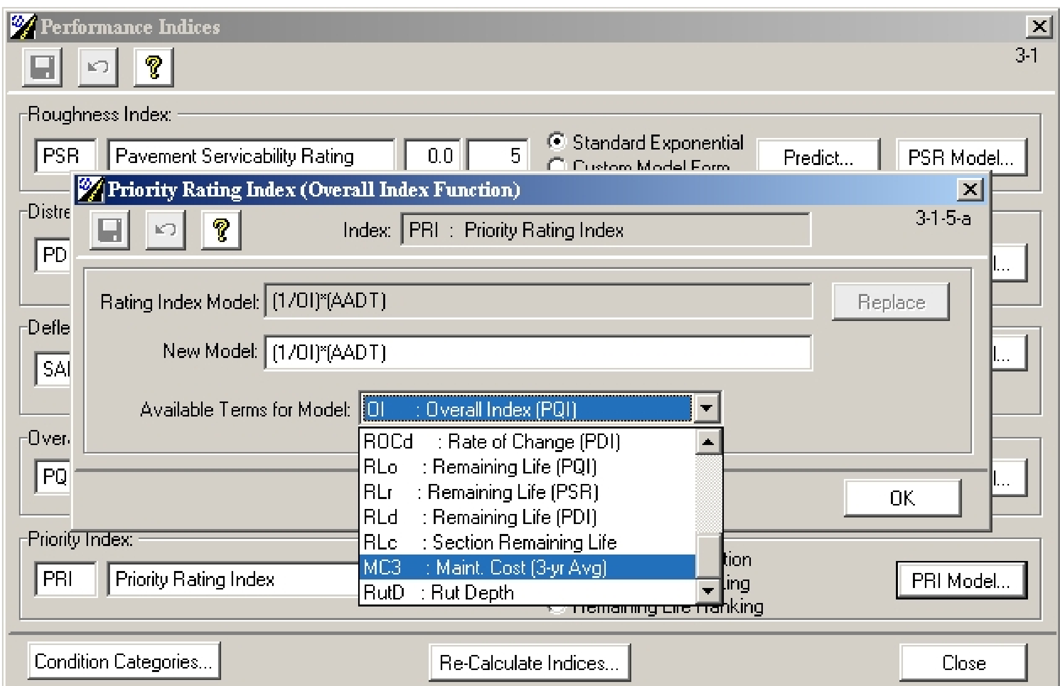

Figure 3.2: Maintenance Cost in the Overall Index Function

3.4 SECTIONAL LEVEL PREDICTION MODELS

Previously the HPMA determined prediction model coefficients for individual sections when building a section data view. Models were either calculated as site-specific models or as default models based on performance class, depending on the available historical data. Once the section models were determined, the user could not modify the individual section models.

ADOT had indicated a need to be able to modify the models for individual sections. The HPMA Function 5-2 (Section Detail Browse) was modified to allow the user to modify the prediction models for a section. The system will then recalculate the future performance of the section.

3.5 FWD BACKCALCULATIONS

HPMA provides overlay thickness calculations for FWD data using the AASHTO models. ADOT had indicated the need to use the ADOT-specific models from the Structural Overlay Design for Arizona (SODA). This alternative was included as an option in the FWD data loading and calculations.

In addition to the calculation procedure, the deflection data browse screen (4-1-14) was modified to allow the user to specify the analysis base year and length of analysis period and recalculate the overlay thickness for the selected subset of deflection data. This required the addition of two new fields in the deflection table to store the analysis base year and length of programming period.

3.6 SUMMARY NETWORK PERFORMANCE PLOT SHOWING IRI

The HPMA Function 4-4 (Highway Network Performance Plot) provides network performance summary plots for various performance indices for roughness, distresses, etc. Based on ADOT's request, an IRI plot was added to this function, in addition to the roughness index defined in the HPMA.

3.7 ADDITIONAL CONSTRUCTION HISTORY DATA ITEMS

The HPMA construction history data, accessed through Function 4-1-17 (Project Details), includes many data items related to the construction and materials. ADOT identified additional data items related to the construction to be included in the database. These items are:

- Percent air voids
- Rice maximum density

The HPMA construction history table was modified to include the additional items.

3.8 MAINTENANCE HISTORY REPORTING

The HPMA Function 5-5 provides a wide variety of section data view reports. Previously, there was no report matching the request for a maintenance history report. The most similar type of report providing the information was the Section History report. However this report was a one page per section report providing all of the data available for a section including history.

A new report format was added to Function 5-5, providing a simpler layout with multiple sections per page and providing the maintenance history from the highway database along with summary performance data for the section data view, as shown in Figure 3.3.

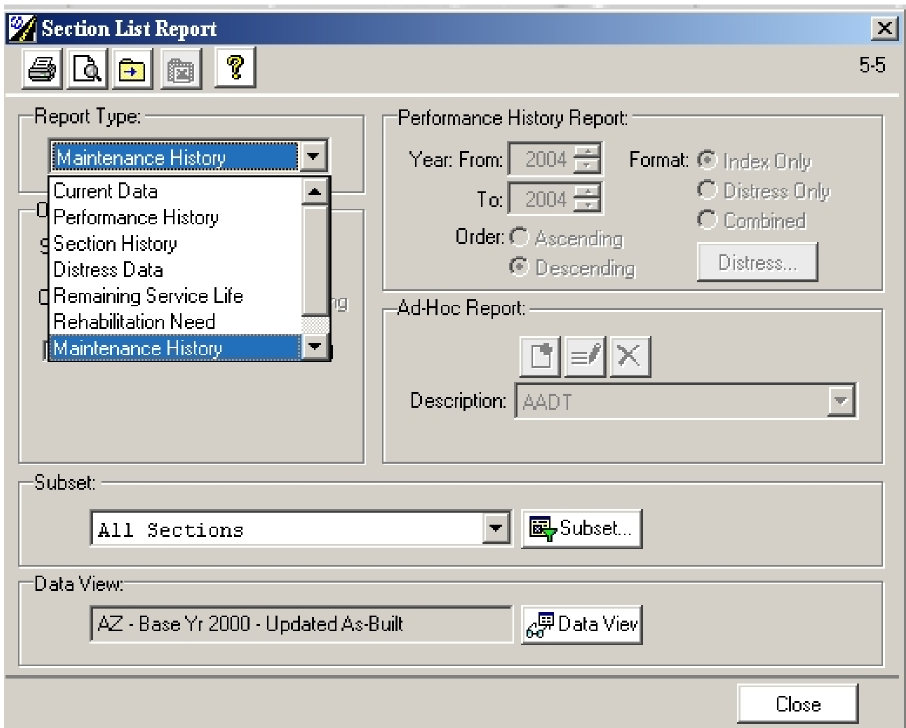

Figure 3.3: Maintenance History Report – Function 5-5

3.9 EXPANSION OF DISTRICT AND MAINTENANCE ORGANIZATION FIELDS

The HPMA includes multiple levels of user-definable jurisdiction types. Jurisdictions Levels 1 and 2 in the ADOT HPMA are the Districts and Maintenance Orgs, respectively. The numeric code fields for these jurisdictions were insufficient in size for the codes used by ADOT. As a result, changes were made to the field sizes as follows:

- Jurisdiction Level 1 - District (HPMA table TAB_REGN) - previously 1 digit - ADOT requested 2 digits.
- Jurisdiction Level 2 - Maintenance Org. (HPMA table TAB_DSRT) - previously 2 digits - ADOT requested 4 digits.

3.10 OPTIMIZATION COST SUMMARY GRAPHIC REPORT

The HPMA optimization reporting includes various text and graphic reports. Previously the cost summary report was only available as a text report. A new graphic report was added that provides cost summary in terms of bar-chart graphs comparing total costs. Three graph options were added to 'ADOT's' HPMA, which are:

1. Total costs by year providing comparison of multiple optimization runs in the same graph (x-axis is years, y-axis is cost, multiple bars within a year represent multiple optimization runs), as shown in Figure 3.4.
2. Total costs by year providing comparison of multiple activities in the same graph (x-axis is years, y-axis is cost, multiple bars within a year represent multiple activities), as shown in Figure 3.5.
3. Total costs by year providing comparison of both multiple optimization runs and multiple activities in the same graph (x-axis is years, y-axis is cost, multiple bars within a year represent multiple optimization runs, bars are stacked color blocks representing multiple activities), as shown in Figure 3.6.

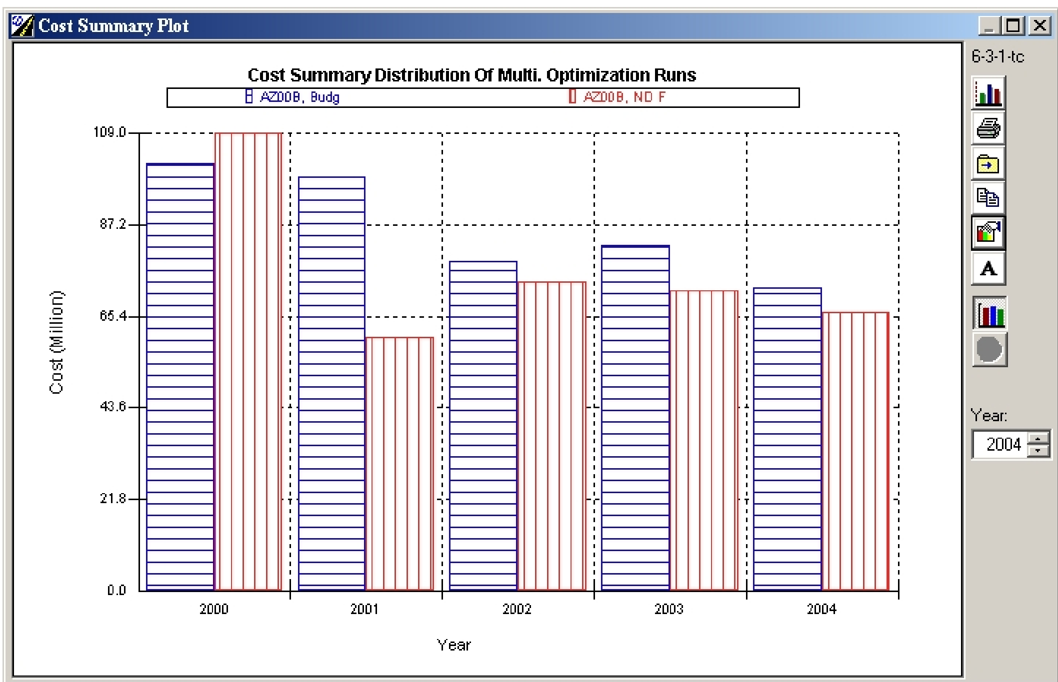

Figure 3.4: Total Cost Comparison of Multiple Optimization Runs

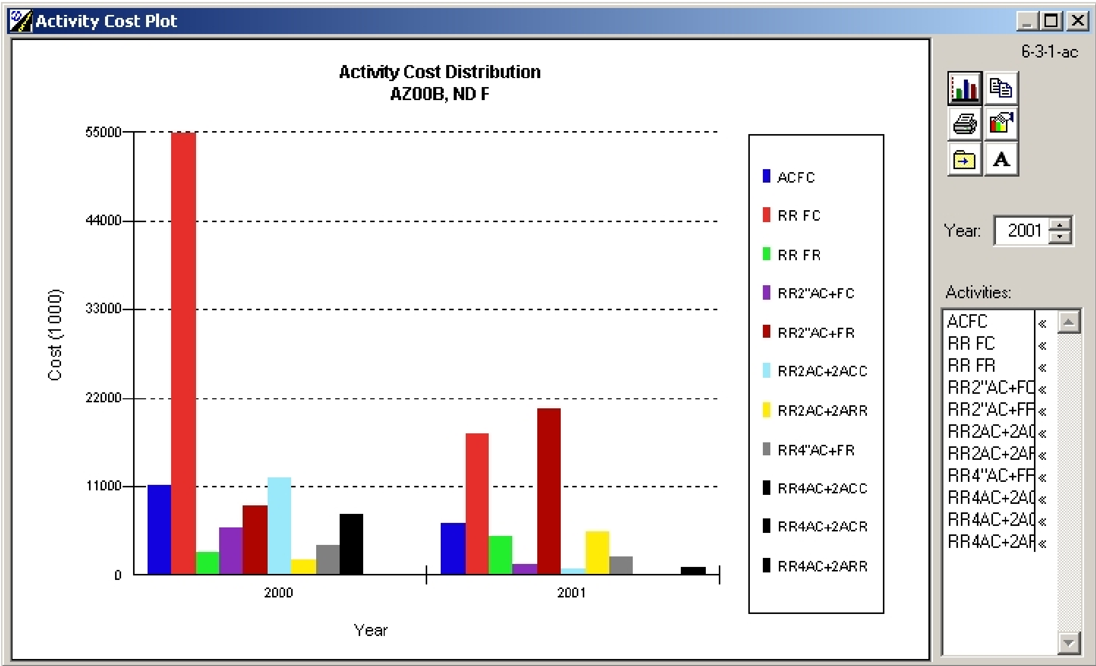

Figure 3.5: Activities Cost Comparison by Year for Multiple Optimization Runs

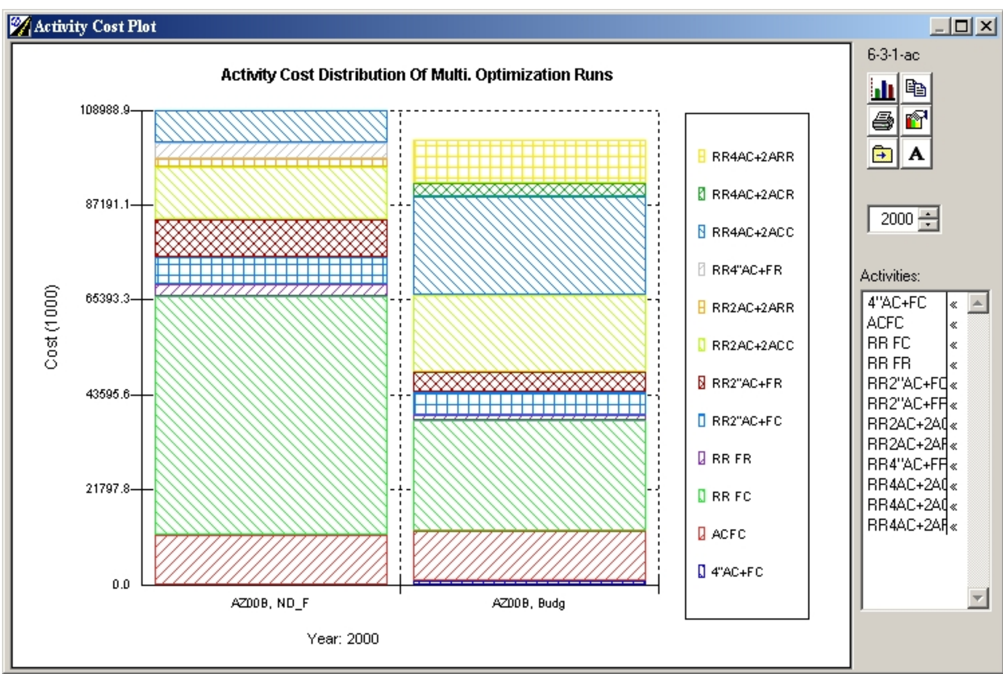

Figure 3.6: Total Cost Comparison by Stacked Activities Costs

3.11 ADDITIONAL FRICTION DATA FIELDS

The ADOT friction data contained more data items than the HPMA friction table. The HPMA highway database friction table Function 4-1-15 was modified to accommodate the additional friction data fields so that all of the information in the source text files could be included in the database.

3.12 NETWORK PERFORMANCE PLOTS BY ROUTE TYPE

The HPMA Functions 4-4 (Highway Network Performance Plot) and 5-7 (Sectional Graphic Report) provide summary network performance plots for various performance indices. Previously, these functions could not produce plots by route type (i.e., Interstate vs. Non-Interstate). However, these functions were modified to accommodate ADOT's requirement to allow for showing the network performance plots by route type.

Function 3-1-cat, which can be accessed from either Function 4-4 and 5-7, was added to the ADOT HPMA, where the condition categories or performance ranges could be defined based on the route type, as shown in Figure 3.7.

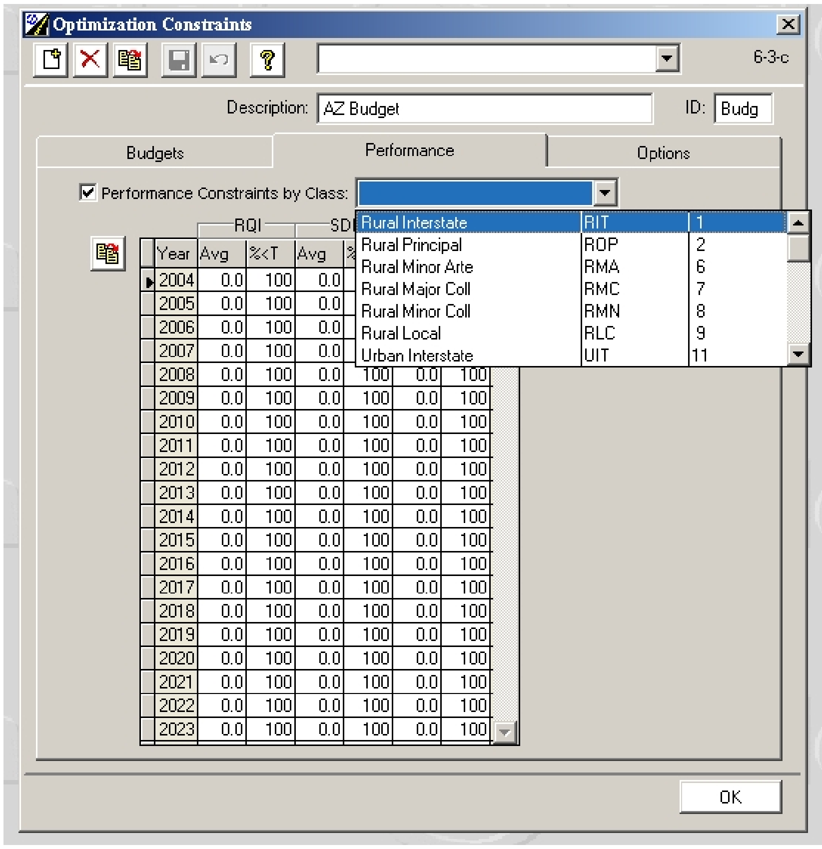

Figure 3.7: Defining Performance Categories by Route Type

3.13 OPTIMIZATION PERFORMANCE CONSTRAINTS BY ROUTE TYPE

The ADOT Pavement Preservation Program has a goal to maintain the PSR at 4.0 for Interstate highways and 3.2 for Non-Interstate highways. Originally, the HPMA was designed to provide the performance constraints during the budget scenario analyses as an overall constraint rather than constraints categorized by route type.

Based on ADOT's requirements, Function 6-3-c was modified to allow defining optimization performance constraints by functional classification, as shown in Figure 3.8

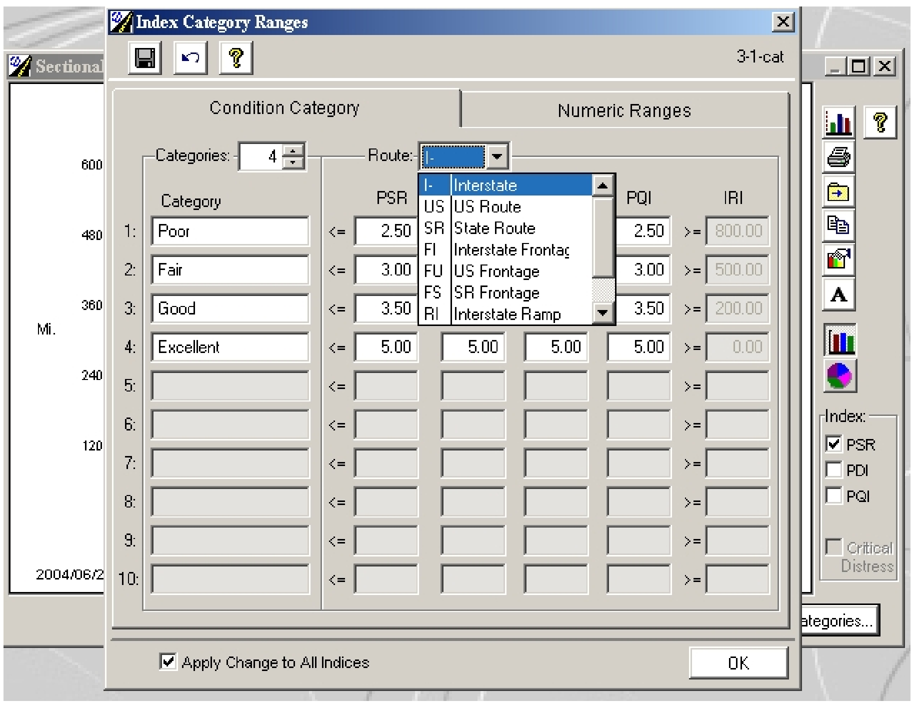

Figure 3.8: Defining Performance Constraints by Functional Classification

4.0 DEVELOPMENT OF PMS DATABASE

The HPMA uses a two-level data model: a detailed highway database, and a de-normalized sectional data view. The source data are loaded and/or maintained in the detailed highway database. The section data views are created within the system through the use of dynamic sectioning utilizing user-defined sectioning parameters.

The detailed highway database includes database tables for each type of roadway data (jurisdictions, geometric, project history, traffic, roughness, distress, etc.) and provides for the storage of historical data for traffic, projects and performance data. This database approach allows the different data types to be stored based on their respective representative segments, rather than forcing a common segmentation approach to fit all data.

The development and implementation of ADOT HPMA involved defining ADOT highway network in the HPMA and then importing the attribute data, including traffic, and historic performance data for each highway section into the HPMA. This task required examining different sources of data in ADOT, customization of data loading modules, populating code tables in the HPMA, and finally loading the required data into the software. In this section, the process of loading the highway referencing, defining the code tables, loading the attributes and historic performance data is described.

4.1 HPMA DATABASE

The HPMA highway database is composed of a set of **database tables** and **code tables**. The database tables, which are described in more details in Section 4.4 of this report and Part A of the report, include tables encompassing the following types of data:

- Highway definitions (start and end mile points, overlaps, etc.)
- Highway landmarks or events (bridges, railroad crossings, intersections, etc.)
- Highway attributes (jurisdiction, administrative, environment, geometrics, shoulders, etc.)
- Traffic data (AADT, ESAL, growth rate, etc.)
- Construction history data (project limits, treatments, layers & materials)
- Performance data (roughness, distress, deflection, friction)
- Images
- Additional construction related tables (cores, Ground Penetrating Radar data)
- Additional tables (documents, programmed work, segment unit costs)

The HPMA code tables define the "pick lists" used within the system. Attributes that have corresponding code tables are limited to the entries in those code tables as being the valid entries. The populated code tables for ADOT are described in the Section 4.3 below.

4.2 DATA SOURCES

Stantec reviewed ADOT's existing pavement management database, maintenance activities database, and all other available relevant databases. The database review was conducted with consideration given to ADOT's existing PMS practices, HPMA system capabilities, and ADOT's desired future PMS practices. In addition, the existing ADOT databases and data sources were reviewed from the viewpoint of an initial population of the HPMA database, as well as future updating methods and sources for the various types of data. The review included the following databases:

1. ADOT Pavement Management Database
2. Arizona Transportation Information System (ATIS) Roads
3. Arizona Highway Log Database
4. ADOT maintenance activities SQL Server based - PECOS
5. Image Data
6. ADOT material's database - FAST
7. Feature Inventory Database
8. Arizona Information Data Warehouse
9. Traffic Data Files

All the data evaluation took place during and after the loading process.

4.3 PARAMETER CODE TABLE

Parameter code tables are defined in the system providing the definitions of various attributes and codes for use in the database. These code tables are used in both the highway database and the section data views. Code tables must be defined prior to loading the data into the highway database, since the loaded data must correspond to these code tables. This process is outlined in Figure 4.1.

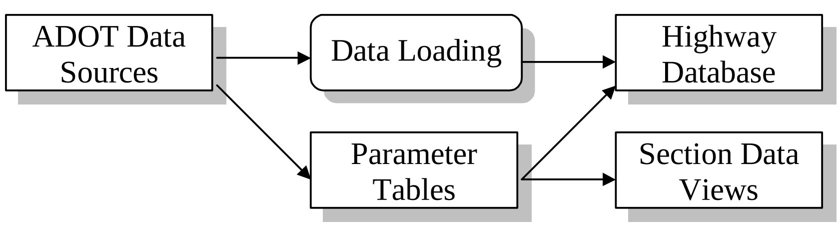

Figure 4.1: ADOT HPMA Database Population

The parameter code tables fall into several categories that can be summarized as follows:

- Highway ID (route types, auxiliary ID, directions)
- Jurisdiction (districts, orgs, counties, COGs, cities)
- Administrative (functional class, elevation zones)

- Environment (environment, terrain)
- Pavement/Median (pavement types, median types)
- Shoulder/Drainage (shoulder types, drainage types, curb types)
- Construction (activities, layer types, material types, etc.)
- Distress Types (defined for each pavement type)
- Traffic Classes
- Deflection Information (device types)

Based on discussions with ADOT, these parameters were finalized and populated with ADOT-specific information. The following subsections describe briefly the parameters' settings in ADOT HPMA. A detailed description of the parameter code tables is shown in Volume 2.

4.3.1 Highway ID and Referencing

The first step in configuring any PMS is developing a way to uniquely identify all of the routes in the network. The HPMA uses the following data items to identify any location on the network:

- Route Types
- Route Number
- Route Auxiliary ID
- Highway Direction
- Mile Post/Reference Nodes

Since the Route Number and Mileposts are displayed as a number, they do not require a list of acceptable values. However, the other items need to be specified in order to correctly identify all routes.

Route Types: The Route Type code table is used to define the route types in the network (for example; Interstate, State Route, etc.). The Route types defined in ADOT HPMA are:

- Interstate Routes I-
- US Routes US
- State Routes SR
- Interstate Frontage FI
- US Frontage FU
- SR Frontage FS
- Interstate Ramp RI
- US Ramp RU
- SR Ramp RS

Route Aux. ID: The Route Aux ID table is used to define the auxiliary ID codes. The auxiliary identifier is typically used to identify business loops, bypasses, alternate routes, etc. The Route Auxiliaries defined in ADOT HPMA are:

- Alternative Route A
- Business Route B
- Loop Route L
- Spur R
- Truck T
- Temporary X
- Wye Leg Y

Highway Directions: The Highway Directions table is used to define the valid directions that are used as part of the unique highway identification. The main purpose of the highway direction field is to separately define multiple sides of a divided highway. The attributes that had to be defined for the Highway Directions table are the direction Code, ID, Description, Pos/Neg (Positive/Negative), and Opp Dir (Opposite Direct).

The direction Code is a numeric identifier. The ID is a 1-character short form that is used on reports and as part of the highway identifier. The Pos/Neg is used to indicate whether the direction is a positive or negative direction. Positive directions have increasing distance reference in the direction of travel. Negative directions have decreasing distance reference in the direction of travel. The Opposite Direction field contains the opposite direction of travel for a route with this direction.

The Direction used on Landmarks checkbox is used to indicate whether highway events / landmarks (highway intersections, bridges, railroad crossings, etc.) in the highway database, use the direction field. When not checked, this means that both sides of a divided highway share the landmarks. For ADOT HPMA, this checkbox is checked.

Referencing: The Referencing field is used to define the type of referencing used, linear referencing, or reference post and offset, as well as to indicate units of measurement and whether ramps are included.

The Linear Referencing Type is defined as one of three types:

- True distance, where the distance referencing represents the actual distance traveled.
- Reference post plus offset, which provides referencing displayed as a post number (often a mile post) plus the distance offset from the reference post (the distance traveled from the reference post).
- Reference Post as a Distance, where the reference, or milepost is considered as an approximate distance and exact distance is defined in the highway landmarks table.

ADOT HPMA uses the third approach for linear referencing of the highway network.

4.3.2 Jurisdiction

Jurisdictions define boundaries of interest for a road segment and typically include districts, counties, etc. The first four levels of jurisdiction are user-definable. The last two are predefined as being Urban Areas and Cities. ADOT HPMA Jurisdiction Tables were configured to define the following jurisdiction levels:

- District
- Maintenance Organization
- County
- Council of Government (COG)
- Urban Areas
- City

Districts / Maintenance Organizations: The districts are geographical regions used to divide up the state. The Districts defined in ADOT HPMA are Phoenix, Tucson, Yuma, Globe, Safford, Flagstaff, Kingman, Holbrook, and Prescott. Also forty-five Maintenance Organizations were defined for ADOT, which are shown in Table A.1 in Appendix A.

County: The County is the third level of jurisdiction defined in ADOT HPMA. This table is used to identify all available counties in the HPMA, which are 15 counties, shown in Appendix A of this report. The attributes that need to be defined for the County Table are the Code, Name, Maintenance Organization, Environment, Subgrade, and Cost Factor. The environment field contains the corresponding environmental region specified in the Environment table. The subgrade field has a default value used for a subgrade condition in this jurisdiction. The cost factor is an adjustment factor for the unit material costs for construction within this jurisdiction.

Council of Governments: Table A.2 in Appendix A shows the eight Councils of Governments (COGs) that were defined in the HPMA.

Urban Areas/Cities: These tables are used to indicate when a road segment is within a city and urban area. Table A.3 in Appendix A lists the three Urban Areas and the eighty-nine cities that were defined for ADOT in the HPMA.

4.3.3 Administrative

The Administrative Tables include the Functional Classifications and the Administrative Classifications. The Functional Classification table contains the list of the valid functional classes along with corresponding default data values. Default data values are used in the system if there is no actual data for a segment. The administrative system can be used to contain a user--defined attribute.

Functional Class: Functional Classes are used to help describe the characteristics of a roadway. This level of route classification is used to help in making assumptions about a route, if measured data is not available. For each functional class, the following default values are used during the analysis if section-specific data is missing:

- AADT - Average Annual Daily Traffic
- % Trucks - Percentage of trucks in the AADT
- Truck Factor - The average ESALs for each truck.
- ESAL - The annual number of Equivalent Single Axle Loads (ESALs).
- GR. Rate - The expected increase (in percent) of traffic annually.
- SN - Default Structural Number for sections within this functional class.
- Activity - Default activity, if not known, used when determining the performance class of a section.
- Width - Default width of a pavement.
- Lane - Default number of lanes assumed to be on a pavement of this class.
- Priority - A factor that can be used in the calculation of the priority index.

It should be noted that the default values were determined based on the results of the statistical analysis performed on the available historic data from ADOT highway network. In case no historic data was available, default values were set based on engineering judgment. Table A.4 in Appendix A shows the list of functional classes along with the set of default values.

Administrative System: The Administrative System Table is a user-definable table that can be used for any type of data. For ADOT HPMA, this table is used to define the elevation zone. Table A.5 in Appendix A shows the attributes of the Administrative System (Elevation Zone).

4.3.4 Environment

Environmental conditions have a significant impact on pavement performance. Therefore, HPMA allows the user to have different performance prediction models for different environmental conditions. The environment code table includes the **Environment Types** and the **Terrain Types**.

Environment Types: Three environmental zones are defined for Arizona, which are Desert, Transition, and Mountain. However, due to the expected difference in performance between sections on Interstate routes and sections on Non-Interstate routes, the environmental zone definition was used to differentiate between these sections. Therefore, six environmental zones were defined, which are:

- Desert -- Interstate
- Transition -- Interstate
- Mountain -- Interstate
- Desert -- Non-Interstate
- Transition -- Non-Interstate
- Mountain -- Non-Interstate

It should be noted that this duplication would not affect any of the data or parameters in ADOT HPMA, but allows for defining different performance prediction models for different route types, within the same environmental zone.

Terrain Types: The three typical terrain types are Flat, Rolling and Rugged. Since ADOT did not have terrain attribute information, this table was not be used during data loading, and the terrain field in the HPMA database is left empty.

4.3.5 Pavement/Median

Pavement type is an essential attribute in HPMA. Most of the M&R analyses are pavement type dependent. Median type provides information on how a highway is divided.

Pavement Types: Pavement types are defined in terms of combinations of surface and base classes. This is usually determined based on factors that significantly affect the performance predictions since the pavement type is one of the factors included in the prediction modeling.

Table A.6 in Appendix A shows the pavement type table and its attributes that were configured for ADOT.

Layer Classes: To define the pavement type, a classification of the surface and base materials is used. These layer classes are to be viewed and modified by clicking on the Define Layer Classes Button. Table A.7 in Appendix A shows the attributes that were defined in the Layer Types for ADOT. The Pavement Class indicates the class of the layer in terms of Bituminous (B), Concrete (C) or Unpaved (U).

Median Types: Table A.8 in Appendix A shows the attributes of Median Type Table, which are the Code, ID, Description, and a divided/undivided checkbox.

4.3.6 Shoulder/Drainage

The Shoulder and Drainage related tables of HPMA contains optional information on additional items that are generally constructed along with a road segment, which may include:

- Shoulders
- Drainage
- Curbs
- Sidewalks

Table A.9 in Appendix A shows Shoulder types that were configured for ADOT.

4.3.7 Construction

The construction parameter code table in HPMA includes four construction related tables, which are:

- Activities
- Materials/layers
- Binders/Aggregates
- Aggregate sources

M&R treatments and their associated unit costs need to be defined in HPMA. In addition, the impact of each treatment on the pavement type has to be defined. For example, an asphalt overlay over a concrete pavement will change the pavement type from concrete pavement to composite pavement. Table A.10 in Appendix A shows the list of M & R treatments and the associated attributes that were defined for ADOT.

All material types that have been used in previous projects and recorded in the construction history table have to be defined in the HPMA prior to data loading. The following attributes have to be defined in the Pavement Materials Table:

- SN factor
- Class
- Type
- Default (Default Thickness): If a layer is known to be present but the thickness is not known, then this value is assumed.
- Min. (Minimum Thickness): This value is the minimum possible thickness for a material of this type.
- Max. (Maximum Thickness): This value is the maximum possible thickness for a material of this type.

Table A.11 in Appendix A shows the list of material types and associated attributes defined for ADOT.

4.3.8 Distress Types

The distress types used in the prediction models vary by pavement type. The following attributes are required for the distress types:

- Measure: This describes the units that are used in measuring the distress.
- Severity: This allows the user to select the number of severity levels defined for each distress type (Low, Moderate and High severity).

Since Arizona records only the extent of the distress and not the severity, only one level of severity is required. The extent of each distress is stored in ADOT HPMA as a percent of the highway area under the low severity level for that distress type. Table A.12 in Appendix A shows the HPMA Distress table that has to be configured for ADOT.

4.3.9 Traffic Classes

The HPMA Traffic Class table defines the traffic classes and the default ESAL factors for bituminous and concrete pavements. This table has to be configured to calculate the ESALs based on classification counts. Table A.13 in Appendix A shows the traffic default values defined for ADOT.

4.3.10 Deflection Testing Information

There are two tables contained within the HPMA to identify the Falling Weight Deflectometer (FWD) equipment and testing parameters. Since all of the data loaded into the ADOT PMS was collected using the FWD, only one entry was required in this table (i.e., FWD).

Typical values for test type include Mid-slab, Approach Slab, and Leave Slab for concrete and composite pavements, and standard for asphalt pavements. For ADOT, the Deflection Test Type table used was Standard only.

4.4 DATA CONVERSION AND LOADING TO HPMA

The HPMA data loading was initially done using a Visual FoxPro (DBF) database. In Phase 4 of the project, the database was transferred to the SQL Server database, as requested by ADOT.

As mentioned earlier, the HPMA highway database is composed of a set of database tables and code tables. The database tables include tables encompassing the following types of data:

- Highway definitions (start and end mile points, overlaps, etc.)
- Highway landmarks or events (bridges, railroad crossings, intersections, etc.)
- Highway attributes (jurisdiction, administrative, environment, geometrics, shoulders, etc.)
- Traffic data (AADT, ESAL, growth rate, etc.)
- Construction history data (project limits, treatments, layers & materials)
- Performance data (roughness, distress, deflection, friction)
- Images
- Additional construction related tables (cores, GPR data)
- Additional tables (documents, programmed work, segment unit costs)

Due to the large number of tables used in the HPMA, a naming convention for the HPMA databases is devised to allow for the identification of different tables. The prefix in the tables' name would indicate the type of data stored within this table. The following prefixes are used in all types of tables:

- RIS = road inventory tables,
- HIS = historical data tables (including the most recent).
- TAB = parameter code tables
- PRM = parameter model coefficients tables

Table 4.1 lists the tables in the highway database. Table 4.2 lists the code tables used in the system. In Table 4.1 the *Data Format* refers to the following: *segment* has a "from" and "to" distance; *point* is at a point location (i.e. no from / to); *data* applies to the related segment through a table relationship.

In Table 4.2 the *Main HPMA Table* refers to the table name in Table 4.1 that the code table relates to.

Table 4.1: HPMA Highway Database Tables with Identified Data Sources

Table Name	Data Type	Data Format	Data Source
RIS_HIWY	Highway definitions	Segment	ATIS Roads DB
RIS_EVNT	Highway landmarks / events	Point	ATIS Roads DB, Highway Log DB
RIS_JURS	Jurisdiction attributes	Segment	Data Warehouse extraction
RIS_ADMN	Administrative attributes	Segment	ADOT_PMS_Tables, Data Warehouse extraction
RIS_GEOM	Geometric attributes	Segment	ADOT_PMS_Tables, Highway Log DB
RIS_SHDR	Shoulder attributes	Segment	Highway Log DB
RIS_ENVR	Environment attributes	Segment	ADOT_PMS_Tables
RIS_SUFF	Sufficiency attributes	Segment	N/A
RIS_ACCT	Accident attributes	Segment	N/A
RIS_PRPH	Peripherals	Segment	N/A
RIS_DOCS	Documents	Segment	N/A
RIS_PGWK	Programmed work	Segment	N/A
HIS_TRAF	Traffic data	Segment	Processed TPD Traffic data file
HIS_STRC / HIS_PROJ / HIS_LAYR	Construction history project data	Segment / Data	ADOT_PMS_Tables // PECOS
HIS_AGGR	Aggregate Sources	Data	N/A
HIS_ROUG	Roughness and rut data	Segment	ADOT_PMS_Tables // Mays text
HIS_DIST	Distress data	Segment	ADOT_PMS_Tables // Condition text
HIS_DEFL	Deflection data	Point	ADOT_PMS_Tables
HIS_FRIC	Friction data	Point	ADOT_PMS_Tables // MuMeter text
RIS_IMAG	Images	Point	Image files
RIS_GPSC	GPS coordinates	Point	GPS centerline database
HIS_CORE / HIS_CORL	Core data / layers	Point / Data	N/A
HIS_GPRS / HIS_GPRL	GPR data segments / layers	Segment / Data	N/A

** N/A indicates not loaded in the ADOT implementation (the tables will exist in the database and can be used in the future).

Table 4.2: Code Tables

Table	Description	Main HPMA Table
TAB_ADMN	Administrative systems	RIS_ADMN
TAB_AGGS	Aggregate Sources	HIS_AGGS
TAB_AUID	Auxiliary Ids	All (Hwy ID field)
TAB_CACT	Binder types	HIS_STRC
TAB_CAGG	Aggregate types	HIS_STRC
TAB_CITY	Cities	RIS_JURS
TAB_CNTY	Counties	RIS_JURS (All (optional Hwy ID field))
TAB_CTYP	Layer types	HIS_LAYR
TAB_CURB	Curb Types	HIS_PRPH
TAB_DDTP	Deflection device types	HIS_DEFL
TAB_DIRC	Directions	All (Hwy ID field)
TAB_DRAN	Drainage types	RIS_SHDR
TAB_DSRT	Districts (jurisdiction level 2)	RIS_JURS
TAB_DTTP	Deflection test type	HIS_DEFL
TAB_ELEC	Electoral districts	RIS_JURS
TAB_ENVR	Environmental zones	RIS_ENVR
TAB_FUNC	Functional classes	RIS_ADMN
TAB_JURL	Jurisdiction types	N/A
TAB_MATL	Material types	HIS_LAYR
TAB_MLDT	Median types	RIS_GEOM
TAB_PAVT	Pavement types	RIS_GEOM
TAB_REGN	Regions (jurisdiction level 1)	RIS_JURS
TAB_ROUT	Route types	All (Hwy ID field)
TAB_SACT	Activities (treatments)	HIS_STRC
TAB_SDWK	Sidewalk types	HIS_PRPH
TAB_SHTP	Shoulder types	RIS_SHDR
TAB_TERR	Terrain types	RIS_ENVR
TAB_TRMD	Treatment modifiers	HIS_STRC
TAB_URBA	Urban areas	RIS_JURS
PRM_DIST	Distress types	HIS_DIST
PRM_ESAL	Traffic classes	HIS_TRAF

5.0 DEVELOPMENT OF PMS MODELS AND ANALYSIS PARAMETERS

In this section, the development of the models required to perform the PMS analysis is described. The development of these models include developing an overall distress index for aggregating the individual distresses, establishing the Maintenance and Rehabilitation (M&R) treatment parameters (unit costs, impacts on pavement performance), and developing pavement performance prediction models.

The PMS analysis process in the HPMA involves three main steps, which are creating a section data view, performing M&R analysis, and performing optimization analyses. Each of these analysis steps requires analysis models that have to be defined before performing the analysis. The creation of the sectional data view requires, in addition to the detailed database and parameter code settings, the pavement performance indices to be defined and the default prediction models to be populated. The M&R analysis and optimization require the decision trees and the cost models for each rehabilitation activity to be defined.

In the following subsections, the development and population of the different analysis models required for the creation of section data views, M&R analysis and optimization are detailed. These models include:

- Pavement Distress Index (PDI) for aggregating distress data
- Default roughness prediction models
- Default cracking prediction models
- Maintenance and Rehabilitation (M&R) decision trees

5.1 OVERVIEW OF HPMA ANALYSIS PROCEDURE

As mentioned earlier, the HPMA uses a two-level data model: a detailed highway database, and a sectional level data view. The detailed highway database includes database tables for each type of roadway data (geometry, projects, traffic, roughness, etc.) and provides for the storage of historical data for traffic, pavement structure and performance data. The section data views are created within the system through the use of dynamic sectioning utilizing user-defined sectioning parameters, or as overrides, where the user defines the section limits to be included. The performance prediction takes place when building the sectional data views (i.e., the sectional database). The HPMA uses the stored performance data for each section to predict the future condition of the "Do Nothing" case, through the use of site-specific models when possible, or through default models in other cases.

M&R analysis and optimization provide a means of developing optimized multi-year work programs as well as for analyzing various funding and performance scenarios. This process is outlined in Figure 5.1.

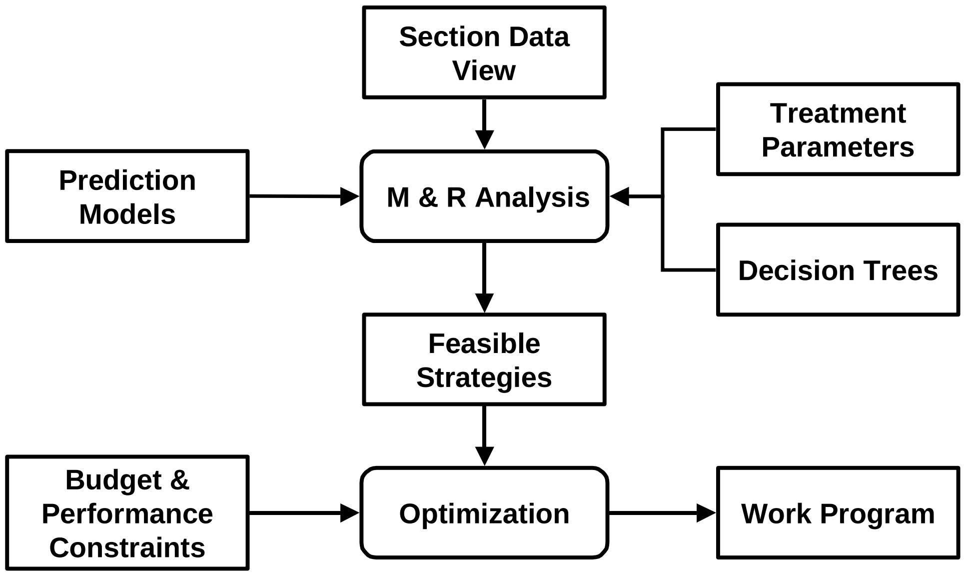

Figure 5.1: M&R Analysis and Optimization

The M&R analysis utilizes user-defined decision trees to determine feasible maintenance or rehabilitation strategies based on the conditions expected to exist at the time. The HPMA uses user-defined decision trees and economic analysis to determine the feasible treatments and the associated costs and benefit (i.e., effectiveness) for each treatment. At this stage, a life cycle analysis of the feasible strategies is performed including performance and costs analysis, based on the user-defined treatment parameters including unit costs.

The M&R analysis results, along with the user-defined budget and/or performance constraints, are used to determine the optimized work programs. The main purpose of the Network Optimization Analysis is determining optimal programs of maintenance and rehabilitation for the network based on the input constraints. The constraints can include funding (budget) constraints and/or performance constraints. The optimization can be executed in a cost-minimization or effectiveness-maximization mode including budget and performance constraints for either mode. As well, the procedure allows switching optimization modes during the programming period. This allows a high degree of flexibility in financial planning and priority programming of maintenance and rehabilitation.

5.2 ADOT PAVEMENT PERFORMANCE INDICES

Since ADOT started using pavement management tools in the early 1980's, pavement performance was mainly defined using a roughness index termed Pavement Serviceability Rating (PSR). Individual surface distresses such as surface cracking and rutting were also used to identify the pavement condition at a more detailed level.

However, PSR was the main measure of pavement performance. It is a decreasing index between 5.0 and 0.0, where 5.0 represent the smoothest possible pavement surface, while 0.0 represents an extremely rough pavement surface. PSR can be related to the International Roughness Index (IRI) using the following equation:

$$PSR = 5 * e^{-0.0038*IRI} \quad \textbf{[5.1]}$$

As part of the development of ADOT PMS2, and to support the incorporation of the preventive maintenance operations within the pavement management tools, an overall Pavement Distress Index (PDI) is developed to aggregate the pavement surface distresses into one index. The development of this model is described in the following section.

5.3 DEVELOPMENT OF PAVEMENT DISTRESS INDEX (PDI)

Surface distress data is collected every year for the entire ADOT highway network. An area of approximately 1000 ft^2 is surveyed at every mile as a sample for this particular mile. Different types of distresses are collected for both AC (flexible/composite) pavements and PCC (rigid) pavements.

To facilitate the analysis, the individual surface distresses are aggregated into one overall index, termed the PDI. The developed PDI aggregates the most prominent distress types into one number, which is indicative of the overall pavement surface condition. PDI can then be used to trigger rehabilitation for pavement sections, or to identify the required rehabilitation activity as part of the M&R decision trees.

After discussion with ADOT, it was decided to consider four individual distresses for the evaluation of the PDI for AC pavements, and three distresses for PC pavements. Table 5.1 shows the distress types considered in the development of PDI for both pavement types. Also shown in the table are the trigger levels and the failure criteria for each distress. For a specific distress type, a trigger level is defined as the level at which a pavement section is flagged for rehabilitation due to that particular distress, while a failure level is defined as the level at which the pavement sections is considered to have failed due to this distress type.

Table 5.1: Surface Distresses for PDI Development

Pavement Type	Distress Type	Extent Measuring Unit	Trigger Level	Failure Level
AC	Cracking	Percentage of area	5%	20%
	Rutting	Inches	0.5"	1.0"
	Flushing	Index (0 through 5), where 5 represents oil-free surface	3.5	2.5
	Patching	Percentage of area	25%	50%
PC	Corner Breaks	Count	5	10
	Transverse Cracking	Count	5	10
	Faulting	Average (in)	0.2"	0.5"

It should be noted that the cracking distress type, mentioned in Table 5.1, is an aggregation of all types of cracking and is considered as a single distress type for the purposes of the development of the PDI. Also, since the severity of these distresses is not evaluated during the surface distress survey, all distresses are assumed to have a low severity and the severity level is not accounted for in the PDI.

During the course of the project, two approaches were proposed to develop the PDI model, which are:

- Approach 1 -- Continuous PDI Function
- Approach 2 -- Deduct Value Model

ADOT has indicated a preference to develop the PDI model using the first approach -- a continuous PDI function. The PDI is developed on a scale from 0.0 to 5.0, where a PDI of 5.0 represents a distress-free pavement surface with perfect conditions.

The PDI model was developed by first defining overall control points. The model form was then defined and the model parameters corresponding to the control points were identified. The control points, defined after consultations with ADOT, are shown in Table 5.2.

Table 5.2: Proposed PDI Control Points

Pavement Condition	PDI Level
Distress Free Surface	5.0
Triggered for Rehabilitation	4.0
Failure Criterion	2.5
Minimum PDI Value	0.0

In the following subsections, the development of the PDI model as a continuous function for both AC and PC pavements is described. Also, the network condition based on the developed PDI and using the historic ADOT distress data is presented.

5.3.1 Development of PDI for AC Pavements

As shown in Table 5.2, PDI for AC pavement is calculated using four distresses, which are cracking, patching, flushing, and rutting. Cracking and Patching are both measured as a percentage of the area, where 0% represents perfect conditions (increasing function). Rutting is a measured total in inches, while Flushing is evaluated on a scale between 0 and 5, where 5 represents perfect conditions (decreasing function). To facilitate the development of the PDI model, individual distresses were normalized, in terms of an index, such that each index is on an increasing scale of 0.0 to 100.0, as follows:

5.3.1.1 Cracking Index (C)

Cracking is an increasing function from 0 to 100. Subsequently, the Cracking Index (C) has the same value of the percentage cracked area.

5.3.1.2 Rutting Index (R)

A rut depth of 2" will be set as the maximum rut depth and all the rutting values are normalized as a percentage of the maximum rut depth using the following equation:

$$R = \frac{RutDepth}{2.0} * 100 \quad \textbf{[5.2]}$$

If the actual measured rut depth is greater than 2.0", the rutting index will be set to 100%.

5.3.1.3 Flushing Index (F)

Flushing is measured on a decreasing scale from 5 to 0. The Flushing Index (F) is an increasing function from 0 to 100, calculated using the following equation:

$$F = 20 * (5.0 - Flushing) \quad \textbf{[5.3]}$$

5.3.1.4 Patching Index (P)

Patching is an increasing function from 0 to 100. Subsequently, the Patching Index (P) will numerically have the same value of the percentage patching.

For the PDI development, Cracking and Rutting were considered as "major" distresses, such that if any of these distresses is triggered or failed, the PDI should reach its trigger or failure level, respectively. As an example if a section has 5% cracking, the PDI should be 4.0, and if the section has 50% rutting, the PDI should be 2.5.

The Flushing and Patching were considered as "minor" distresses. If any of these distresses reach a failure level, the PDI will reach a trigger level. As an example, if a section has 50% Patching, then the PDI should be 4.0.

A continuous function was developed to satisfy these constraints, such that each distress index is represented by a linear coefficient and raised to a power to represent the different weights of the distresses and scale each distress index to conform to the PDI scale. The following equation represents the PDI function for AC pavements.

$$PDI = 5.0 - (0.345C^{0.66} + 0.0142R^{1.32} + 0.005F^{1.36} + 0.02P^{1.0} - 0.0823C^{0.18}R^{0.50}) \quad \textbf{[5.4]}$$

It should be noted that the PDI function includes a term combining the effect of the major distresses, i.e. rutting and cracking, to account for the possible cases of overlapping cracking and rutting. Table 5.3 shows a number of cases for a combination of distresses and the resulting PDI.

Cases 1 though 9 in Table 5.3 represent the constraints used to develop the PDI model. As can be noted, the major distresses have higher contribution to the overall PDI than the minor distresses. Cases 10 through 20 are samples from actual data extracted from historic ADOT distress data already loaded to ADOT PMS.

Table 5.3: Sample Distress Combinations and Corresponding PDI for AC Pavements

Case	Distress Data				Distress Indices				PDI
	Cracking	Rutting	Flushing	Patching	C	R	F	P	
A1	0	0	5.0	0	0	0	0	0	5.0
A2	5%	0	5.0	0	5	0	0	0	4.0
A3	20%	0	5.0	0	20	0	0	0	2.5
A4	0	0.50"	5.0	0	0	25	0	0	4.0
A5	0	1.00"	5.0	0	0	50	0	0	2.5
A6	0	0	3.5	0	0	0	30	0	4.5
A7	0	0	2.5	0	0	0	50	0	4.0
A8	0	0	5.0	25%	0	0	0	25	4.5
A9	0	0	5.0	50%	0	0	0	50	4.0
A10	0	0.11"	5.0	0	0	6	0	0	4.9
A11	6%	0.05"	4.0	0	6	3	20	0	3.7
A12	0	0.60"	4.0	0	0	30	20	0	3.4
A13	30%	0.16"	4.0	0	30	8	20	0	1.7
A14	0	0.12"	5.0	0	0	6	0	0	4.9
A15	45%	0.13"	4.0	0	45	7	20	0	0.7
A16	5%	0.45"	4.5	85%	5	23	10	85	1.9
A17	0	0.17"	5.0	25%	0	9	0	25	4.3
A18	25%	0.27"	3.0	0	25	14	40	0	1.5
A19	2%	0.85"	5.0	0	2	43	0	0	3.1
A20	15%	0.17"	3.5	0	15	9	30	0	2.59

The PDI described in Equation [5.4] was implemented in ADOT HPMA. However, as a result of the statewide analysis, which is described in Section 6.0, and due to the fact the ADOT traditionally evaluated the pavement surface condition primarily in terms of cracking, using the PDI as a function of cracking only provided better results and more accurately matched historic ADOT data. Consequently, the PDI was modified to be a function of Cracking only, as opposed to be a function of the above four distresses, as follows:

$$PDI = 5.0 - (0.345C^{0.66}) \qquad \textbf{[5.5]}$$

It should be noted, however, that the other distress types are available in ADOT HPMA and can be utilized in the system if the need arises or if ADOT modified their distress data collection procedures to cover other distress types, extents, and/or severities.

5.3.2 Development of PDI for PC Pavements

As mentioned earlier, surface distress data is collected every year for the entire ADOT highway network. For PCC pavements, an area of approximately 1000 ft^2 is surveyed at every mile as a sample for this particular mile for cracking, patching and spalling. Faulting data is collected with roughness data as average and standard deviation of faulting value.

Cracking is collected by counting the number of transverse cracks (maximum of 15 cracks per section), longitudinal cracks, and corner breaks. Patching is evaluated as a percentage of the area, while spalling is evaluated on a scale from 0 to 5, as follows:

0: No Spalling   1: Severe Spalling   3: Moderate Spalling   5: Low Spalling

Only three distresses are used to calculate the PDI for PC pavements, which are the corner break, transverse cracks, and faulting. Spalling was not considered in the PDI because of its inverted scale of measurement; which made it difficult to incorporate in the PDI.

Due to the very limited amount of historic performance data for rigid pavement sections, it was not possible to develop a PDI model based on actual historic data. The PDI development had to rely mainly on engineering judgment. Of the 172,000 historic records that were loaded to the ADOT HPMA, there were only 20 records of PCC pavement distress data.

A continuous function was developed to satisfy the constraints shown in Table 5.2, such that each distress index is represented by a linear coefficient and raised to a power to represent the different weights of the distresses and scale each distress index to conform to the PDI scale. The following equation represents the PDI function

$$PDI = 5.0 - (5.0 * FT + 0.119 * CB^{1.322} + 0.119 * TC^{1.322}) \qquad \textbf{[5.6]}$$

Table 5.4 shows a number of cases for a combination of distresses and the resulting PDI for PC pavement sections. The cases shown in the table are for illustration and are not actual measured distresses for sections in ADOT's highway network.

Table 5.4: Sample Distress Combinations and Corresponding PDI for PC Pavements

Case	Distress Data			PDI
	CB	TC	FT	
A1	0	0	0	5.0
A2	5	0	0	4.0
A3	10	0	0	2.5
A4	0	5	0	4.0
A5	0	10	0	2.5
A6	0	0	0.2	4.0
A7	0	0	0.5	2.5
A8	3	2	0.15	3.4
A9	7	4	0.30	1.2
A10	3	1	0.75	0.6
A11	5	5	0.0	3.0
A12	3	4	0.25	2.5

5.4 MAINTENANCE AND REHABILITATION ACTIVITIES

As shown earlier in Figure 5.1, the M&R treatment parameter is an important input to the M&R analysis. The list of M&R activities implemented in ADOT HPMA was defined after several meetings with ADOT staff and took several revisions and refinements to reach its final form.

Table 5.5 shows the final list of the M & R activities implemented in the ADOT HPMA. In this table, the activity type, the pavement type to which the treatment can be applied to and the unit cost for each activity are shown. These unit costs were defined after extensive discussions with ADOT staff, based on average 2003 costs. However, it is recommended that these costs be revised on a yearly basis, to ensure accurate budget scenario analysis results.

The following are the four M&R types that are recognized in HPMA.

- M -- Localized maintenance activity
- G -- General maintenance activity
- R -- Rehabilitation activity
- C -- Construction activity

It is important to accurately define the activity type in the HPMA because it affects the manner by which the activity is modeled in the analysis.

Table 5.5: Maintenance and Rehabilitation Activities

HPMA Code	HPMA ID	Description	HPMA Type	Pavement Type	Unit Costs ($/Yds^2)
101	Patch	Premix Patch	M	AC, CO	12.00
102	Level	Level with Premix	G	AC, CO	3.20
103	CrkSeal	Crack Seal	M	AC, CO	2.00
104	SandSeal	Sand Seal	G	AC, CO	1.44
105	FDPtch	Rep Surf/Base	M	AC, CO	16.00
106	ChipSeal	Chip Seal	G	AC, CO	1.78
107	SealCoat	Seal Coat	G	AC, CO	1.78
108	Flush	Flush Coat	G	AC, CO	0.25
109	SpotFlush	Spot Flush/Seal	M	AC, CO	3.20
110	Joint Seal	PC slab joint sealing	M	PC	8.00
111	Patch(E)	Premix Patch Emrg.	M	AC, CO	12.00
112	TightBlade	Tight Blading	M	PC	6.00
113	CrkSeal-R	Crack Seal with Rubber	M	AC, CO	6.00
114	PC-RepR	PCC Repair/Replace	M	PC	15.00
115	PC-SpRep	PCC Spall Repair	M	PC	12.00
119	PvSrfMnt	Pvd Surf Maint.	M	AC, CO	12.00
120	DG+FC	Diamond Grind + Friction Course	G	PC	12.98

HPMA Code	HPMA ID	Description	HPMA Type	Pavement Type	Unit Costs ($/Yds^2)
121	Dbl Chip S	Double Chip Seal	G	AC, CO	2.56
123	MicroSurf	Micro Surfacing	G	AC, CO	3.50
124	Slurry	Slurry Seal	G	AC, CO	1.60
125	ScrubSeal	Scrub Seal	G	AC, CO	1.30
126	Dl Retr+JS	Dowel Retrofit + Joint Seal	M	PC	12.00
127	FogS-S	Fog Seal -- Regular AC	M	AC, CO	1.28
128	FogS-R	Fog Seal -- Rubberized	G	AC, CO	1.38
129	RM+Seal	Rubber Membrane + Sealing	G	AC, CO	2.50
141	CkFl+Seal	Crack Fill and Seal Coat	G	AC, CO	4.50
201	ACFC	Friction Course AC	R	AC, CO	3.50
202	ARFC	Friction Course AR	R	AC, CO	4.00
203	BTS	Bit. Treat Surf 2 in	R	AC, CO	2.00
206	RR FC	R&R Friction Course	R	AC, CO	4.50
207	RR FR	R&R Rbr Friction Crs	R	AC, CO	5.50
208	RR SC	R&R Seal Coat	G	AC, CO	2.50
211	RR2"+SC	Mill/Rep 2"AC+SC	R	AC, CO	11.00
212	RR2"AC+FR	Mill/Rep 1.5-3"AC+FR	R	AC, CO	12.96
213	RR2"AC+FC	Mill/Rep 1.5-3"AC+FC	R	AC, CO	11.88
214	RR2"AR+FR	Mill/Rep 1.5-3"AR+FR	R	AC, CO	14.63
215	RR4"AC+FR	Mill/Rep 3-5"AC+FR	R	AC, CO	16.00
216	RR4"AC+FC	Mill/Rep 3-5"AC+FC	R	AC, CO	15.00
217	RR4"AR+FR	Mill/Rep 3-5"AR+FR	R	AC, CO	19.00
218	RR4"AC+SC	Mill/Rep 3-5"AC+SC	R	AC, CO	14.50
219	RR5"AC+FR	Mill/Rep >5"AC+FR	R	AC, CO	18.00
221	2"AC+SC	1.5-2.5"AC + SC	R	AC, CO	9.07
222	2"AC+FR	1.5-3.0"AC + FR	R	AC, CO	10.85
223	2"AC+FC	1.5-3.0"AC + FC	R	AC, CO	9.88
224	3"AC+SC	2.5-3.5"AC + SC	R	AC, CO	11.50
225	3"AC+FR	2.5-3.5"AC + FR	R	AC, CO	13.28
226	3"AC+FC	2.5-3.5"AC + FC	R	AC, CO	12.31
227	4"AC+SC	3.0-5.0"AC + FR	R	AC, CO	16.93
228	4"AC+FR	3.0-5.0"AC + FC	R	AC, CO	15.96
229	4"AC+FC	3.0-5.0"AC + SC	R	AC, CO	15.15
231	RR2AC+2ACC	RR1.5-3AC+1.5-3AC+FC	R	AC, CO	16.75
232	RR2AC+2ACR	RR1.5-3AC+1.5-3AC+FR	R	AC, CO	17.50
233	RR2AC+2ARR	RR1.5-3AC+1.5-3AR+FR	R	AC, CO	18.96
234	RR2AR+2ACR	RR1.5-3AR+1.5-3AC+FR	R	AC, CO	18.96
235	RR2AR+2ARR	RR1.5-3AR+1.5-3AR+FR	R	AC, CO	25.35
236	RR4AC+2ACC	RR3-5"AC+1.5-3"AC+FC	R	AC, CO	19.26
237	RR4AC+2ACR	RR3-5"AC+1.5-3"AC+FR	R	AC, CO	22.44

HPMA Code	HPMA ID	Description	HPMA Type	Pavement Type	Unit Costs ($/Yds^2)
238	RR4AC+2ARR	RR3-5"AC+1.5-3"AR+FR	R	AC, CO	29.32
239	RR4AR+2ACR	RR3-5"AC+3-5"AC+FR	R	AC, CO	31.75
241	OL2R	Overlay <=3" Recyc	R	AC, CO	8.51
242	OL4R	Overlay 3-5" Recyc	R	AC, CO	14.18
251	RM+OL2	RbrM+Overlay <=2.5	R	AC, CO	12.56
252	RM+OL3	RbrM+Overlay > 2.5	R	AC, CO	14.99
253	RR+RM+OL	RR1.5+RbrM+Ovrly3	R	AC, CO	18.06
261	2"AC	1.5-2.5"AC	R	AC, CO	7.29
262	3"AC	2.5-3.5"AC	R	AC, CO	10.94
301	Crk&Seat	Crack & Seat + Ovly	C	PC	26.00
302	JtRep+Ovly	Jt & Slab Rep. + Ovly	R	PC	15.00
401	ConOL	Concrete Ovly	C	AC, CO, PC	12.00
501	OC-Bit	Orig. BIT Construction	C	AC, CO, PC	30.00
502	OC-BCB	Orig. BCB Construction	C	AC, CO, PC	31.00
503	OC-CON	Orig. CON Construction	C	AC, CO, PC	44.00
504	OC-CRC	Orig. CRC Construction	C	AC, CO, PC	44.00
505	OC-CDP	Orig. CDP Construction	C	AC, CO, PC	46.00
510	Rec-AC	Reconstruct AC	C	AC, CO, PC	30.00
515	Rec-Con	Reconstruct Concrete	C	AC, CO, PC	43.00

5.5 MODELING THE IMPACT OF MAINTENANCE AND REHABILITATION ACTIVITIES ON PAVEMENT PERFORMANCE

The impact of M&R activities on future pavement performance is typically modeled either as an improvement of the pavement condition, or a slower rate of deterioration. Modeling the improvement in the pavement condition (i.e., jump) requires a prediction curve. Modeling the slower rate of deterioration is done in two ways; either by a flatter prediction curve or by "holding" the condition of the pavement for a certain period.

In the ADOT HPMA, the impacts of the implementation of an R or C type activity are modeled as "jumps" or increase in the pavement condition on the performance curves as shown in Figure 5.2. As can be noted from the figure, these jumps bring the pavement to the condition of a newly constructed section.

The impacts of implementing an M or G type activity are modeled differently than the R and G type activities. The impacts are represented by a jump or increase in the pavement condition, in addition to a holding period, where the pavement condition is held constant. Figure 5.3 depicts how the M and G type activities are modeled. It should be noted that the increase or the jump for M and G type activities does not bring the pavement to the newly constructed condition.

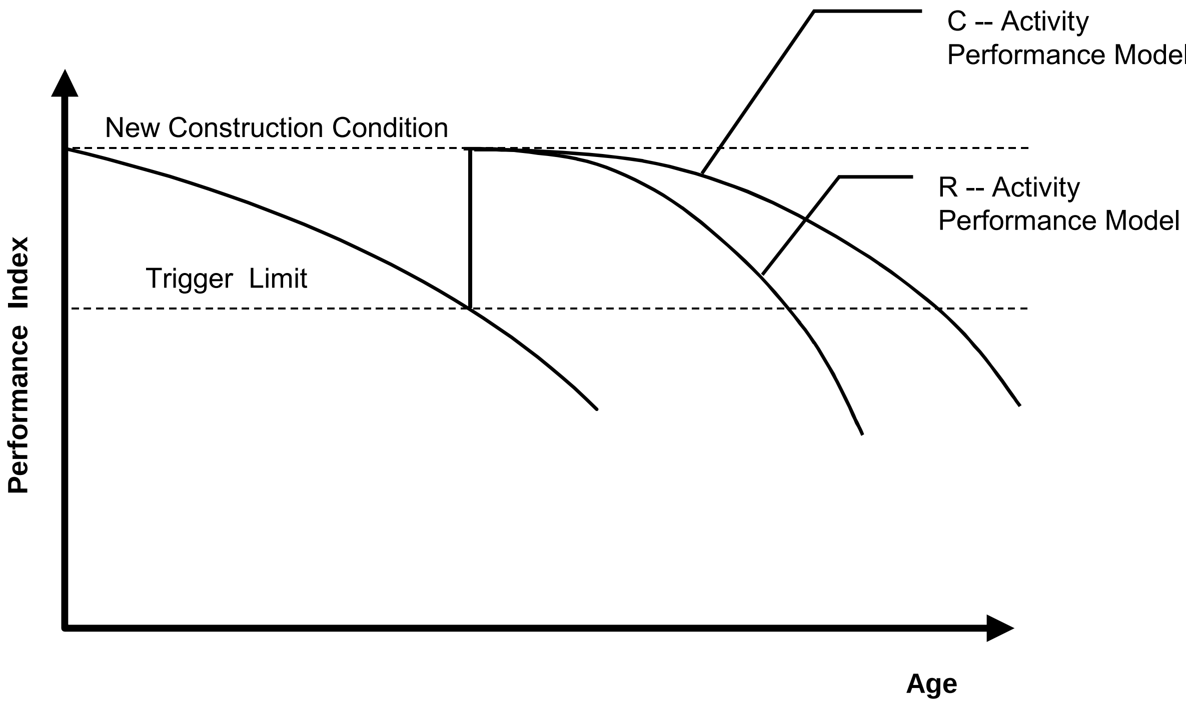

Figure 5.2: Impact of R and C Activities

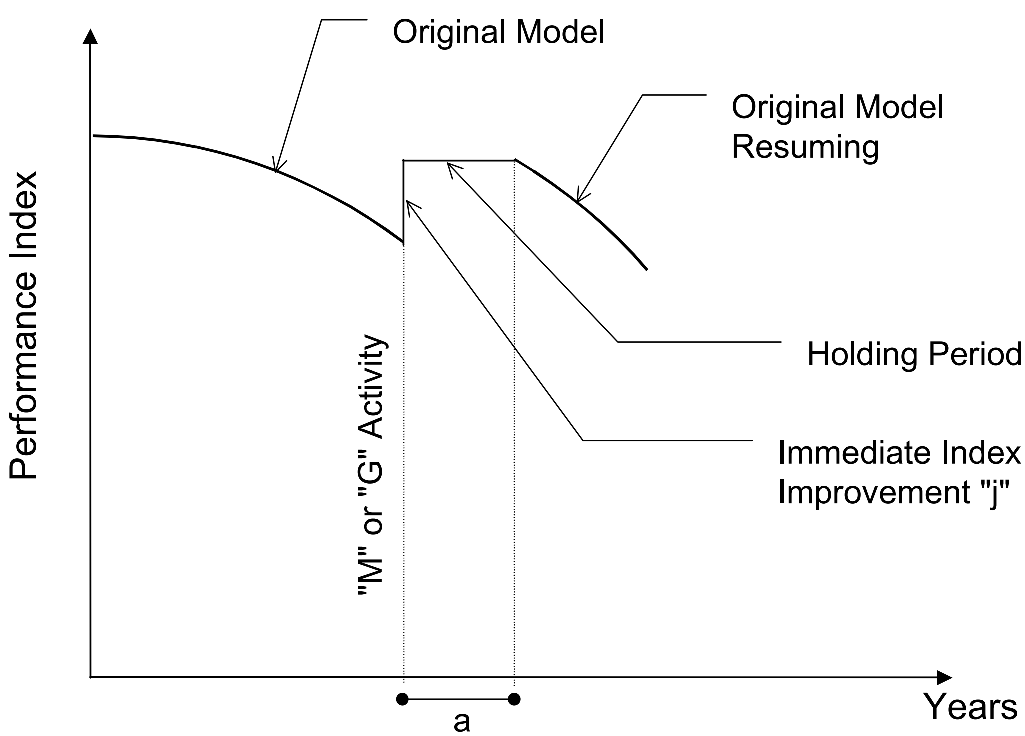

Figure 5.3: Maintenance Activities as Holding Strategies

Table 5.6 shows the holding periods and PSR improvements for the maintenance activities as included in ADOT HPMA. The values shown the in the table are based on discussions with ADOT staff. These jumps and/or the holding periods should be revised when enough performance data for these maintenance activities are available.

Table 5.6: Condition Improvement and Holding Period for G and M Activities

Code	Activity	Type	Unit Costs ($/Yds^2)	Holding Period "a" (Yrs)	PSR Improvement "j"
101	Premix Patch	M	12.00	2	0.5
102	Level with Premix	G	3.20	3	0.5
103	Crack Seal	M	2.00	3	0.4
104	Sand Seal	G	1.44	2	0.4
105	Rep Surf/Base	M	16.00	4	1.0
106	Chip Seal	G	1.78	3	0.5
107	Seal Coat	G	1.78	3	0.5
108	Flush	G	0.25	4	0.4
109	Spot Flush/Seal	M	3.20	2	0.4
110	Joint Seal	M	8.00	5	0.7
111	Premix Patch Emrg	M	12.00	2	0.5
112	Tight Blade	M	6.00	2	0.3
113	Crack Seal w/Rubber	M	6.00	4	0.7
114	PCC Repr/Repl	M	15.00	7	1.0
115	PCC Spall Repr	M	12.00	7	1.0
119	Pvd Surf Maint	M	12.00	7	1.0
120	Diamond Grind + FC	G	12.98	5	1.0
121	Double Chip Seal	G	2.56	2	0.5
123	Micro Surfacing	G	3.50	3	0.5
124	Slurry Seal	G	1.60	3	0.4
125	Scrub Seal	G	1.30	3	0.3
126	Dowel Retrofit	M	12.00	8	1.0
127	Fog Seal -- S	G	1.28	3	0.3
128	Fog Seal -- R	G	1.38	3	0.3
129	Rubber Mem. + SC/FL	G	2.50	7	0.5
141	Crack fill & Seal Coat	M	4.00	5	0.5

5.6 DEVELOPMENT OF PSR DEFAULT PREDICTION MODELS

The HPMA utilizes two approaches for predicting future pavement performance, which are the site-specific prediction and the default approaches. The site-specific modeling approach is based on the use of historical performance data to develop model coefficients for individual analysis sections. For each individual section, the available historical performance data since the last rehabilitation or construction is analyzed to determine the model that matches the observed performance of the section, and thus predict the future performance.

The default prediction models are used in the following cases:

- In the absence of adequate historic data for the generation of site specific models
- When the site-specific models do not meet the acceptance criteria
- For predicting the pavement performance under future rehabilitation activities

Default prediction models are developed using the family-of-models approach, where future performance of pavement sections within the same performance class is modeled using one performance model.

In the following subsections, the development of the roughness default models based on historic performance data and using the family-of-models approach is described. The performance classes are first defined and then extraction and analysis of historic data is presented. Finally, the development and adjustment of the models is described.

5.6.1 Performance Classes

In the family-of-models approach, pavement sections that have common characteristics such as pavement type, traffic levels, etc. are grouped into performance classes. The following are the performance classes considered in the HPMA:

- Last rehabilitation activity
- Pavement Type
- Environment Conditions (3 classes)
- Traffic (3 classes)
- Subgrade Condition (3 classes)
- Structural Thickness (3 classes)

In addition, the functional class is also considered (Interstate and Non-Interstate). Two sets of performance models were developed for these two functional classes.

5.6.1.1 Models Naming Convention

Due to the large number of possible combinations for model development, a numbering scheme was devised to allow easy referencing of these models. An 8-character identification number is assigned to each model as follows:

- Activity Type - Characters 1-3
- Pavement Type - Character 4
- Environment Class - Character 5
- ESAL Class - Character 6
- Subgrade Class - Character 7
- Thickness Class - Character 8

As an example, prediction model number 231-13231 is the performance model describing the expected performance of activity number 231 (RR1.5-3AC+1.5-3AC+FC) for pavement type 1, environment class 3, subjected to traffic class 2, with a subgrade strength from class 3, and a thickness class 1. If a specific class is not defined, corresponding digit is set to zero. As an example, prediction model number 231-13000 is the performance model describing the expected performance of treatment activity number 231 for pavement type 1 and environment class 3, for all traffic, subgrade, and thicknesses.

5.6.1.2 Mathematical Model Form

A sigmoidal (i.e. S-shaped) form is used within the HPMA for modeling the pavement performance. This model form has a greater degree of flexibility in describing the deterioration of a section. The following is the sigmoidal model form used in the HPMA for performance prediction modeling:

$$PSR = O - e^{\left(A - B \cdot C^{\ln\left(\frac{1}{Age}\right)}\right)} \qquad \textbf{[5.7]}$$

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

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

5.6.2 Performance Model Generation Procedure

The performance model generation involves data manipulation and the use of procedures to individually inspect and validate all models. The variation in the available data does not always provide the desired models. Therefore, engineering judgment based on experience and feedback from ADOT was used. The following section outlines the procedure followed for generating the required performance models.

Non-linear regression analysis techniques were used to develop performance models for the rehabilitation activities where enough good historical data points are available. Engineering judgment was used to adjust some of these models to accommodate the conditions of activities with insufficient historical data.

5.6.2.1 Historical Data Extraction

The performance models are typically generated from historical performance and project data stored in the HPMA. This data is extracted from the HPMA and used to provide the required performance models for the different pavement rehabilitation treatments.

Performance data was assembled for homogenous sections by performance class. All of the available segments with activities and performance data were assigned to performance classes based on the class related data. The data used in this study represents the last 20 years of data currently available.

5.6.2.2 Data Filtering

To ensure the development of the best possible models, all ADOT's performance data had to go through some Quality Assurance (QA) control checks. For roughness data, an acceptance criterion was established to remove data outliers and segments exhibiting unexpected behavior. A filtering criterion was established to remove this kind of data, which might unfairly bias the regression statistics.

Filtering limits used to exclude outlier data are shown in Table 5.7 in terms of both IRI and Pavement Serviceability Rating (PSR), where the relationship between IRI and PSR is shown by the following equation. Figure 5.4 shows the same limits for the PSR.

$$PSR = 5.e^{-0.0038.IRI} \quad [5.8$$

Table 5.7: Roughness Data Filtering Limits

Age	Lower Limit		Upper Limit	
	IRI	PSR	IRI	PSR
0	94	3.5	28	4.5
10	>>	0	94	3.5

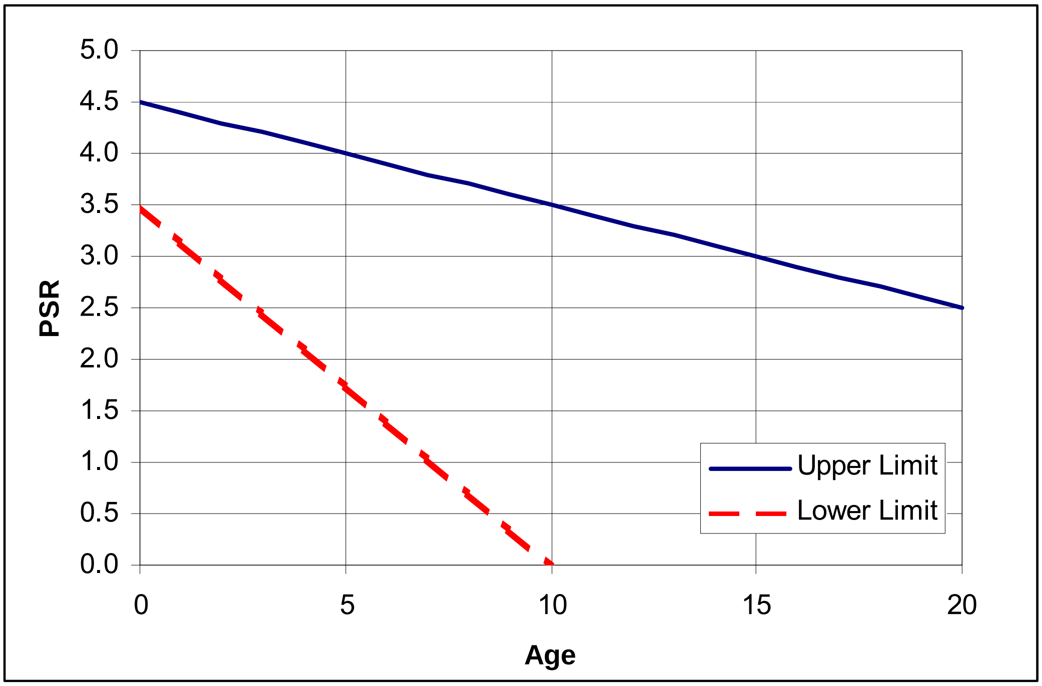

Figure 5.4: Roughness Outlier Limits

5.6.2.3 Data Classification

As mentioned earlier, a separate model should be developed for each combination of the rehabilitation activity, pavement type, functional classification, environment class, traffic class, subgrade class, and thickness class. However, based on the historic data from ADOT, some of these combinations were not applicable.

Since subgrade information is not available in ADOT databases, the subgrade was not used. However when this data is available in the future, these models can be adjusted to account for different subgrade conditions.

The investigation conducted on the historical data indicated that developing separate models for the different traffic and thickness classes is not warranted. The regression models developed based on these classes were not significantly different.

The effect of the environment was investigated prior to model generation to identify whether the environment zone has a significant effect on the pavement performance. Figure 5.5 through Figure 5.7 shows the historic PSR data points for all rehabilitation activities on flexible pavement sections on Interstate highways in the Desert (DS), Transition (TR), and Mountain (MT) zones, respectively. Figure 5.8 shows a comparison of the regression models for these zones. As can be noted from the figures, the pavement performance in the TR and MT is very close, while the pavement performance in the DS zone is different than those in the other zones.

Similarly, Figure 5.9 through Figure 5.11 show the historic data points and the regression analysis results for the all rehabilitation activities on flexible pavement sections on Non-Interstate routes in DS, TR, and MT zones, respectively. Figure 5.12 shows a comparison of the regression models for these zones. These figures confirm that the pavement performance in the TR and MT is very close, while the pavement performance in the DS zone is different than those in the other zones.

Based on the results shown in previous figures, only two environment zones are considered in the analysis, which are the Desert Zone and the Non-Desert Zone (including both the Transition and the Mountain zones). Also due to the differential performance between Interstate routes and Non-Interstate routes, the environmental zones will be duplicated, such that the environment/functional class combinations analyzed are:

- Class 1 -- Interstate sections in Desert Zone (D-I)
- Class 2 -- Interstate sections in Transition and Mountain Zones (ND-I)
- Class 3 -- Non-Interstate sections in Desert Zone (D-NI)
- Class 4 -- Non-Interstate sections in Transition and Mountain Zones (ND-NI)

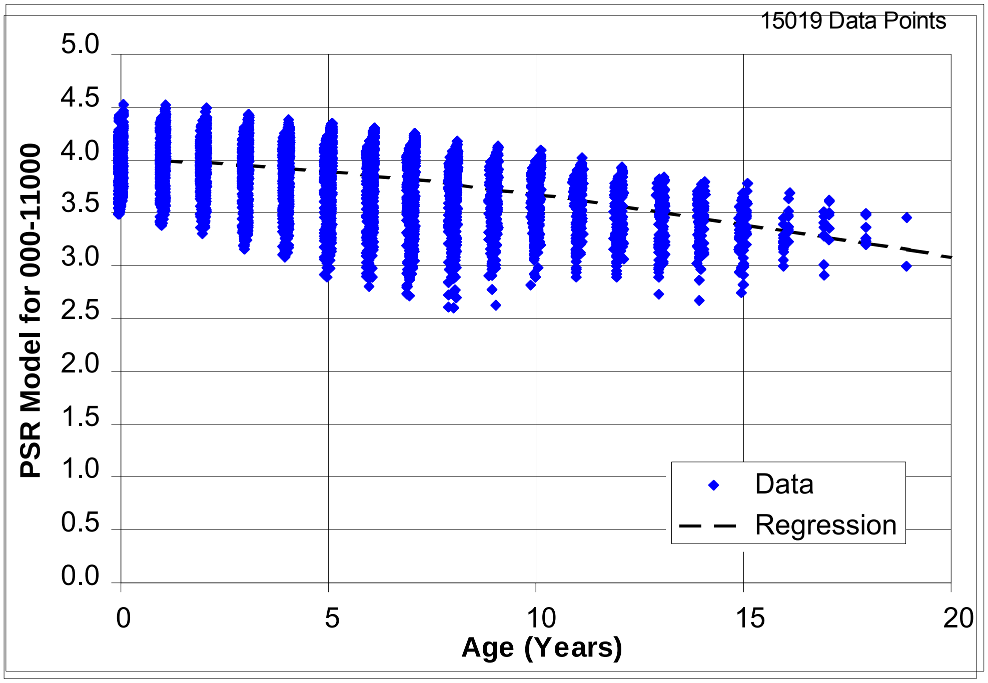

Figure 5.5: Interstate Historic Roughness Data in the Desert Zone

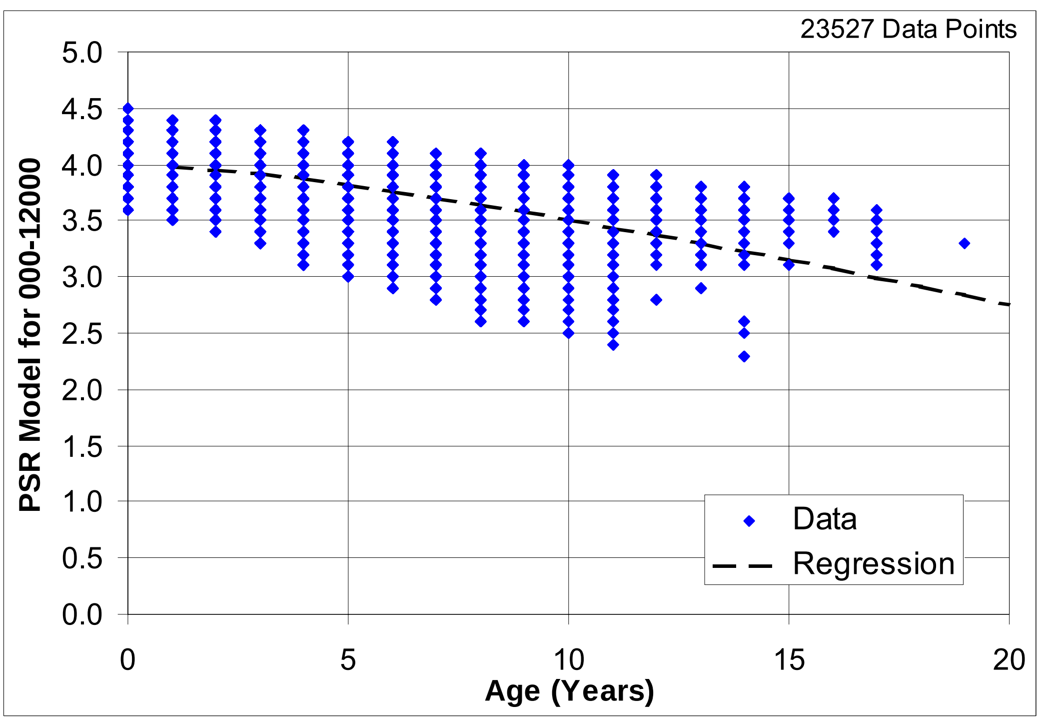

Figure 5.6: Interstate Historic Roughness Data in the Transition Zone

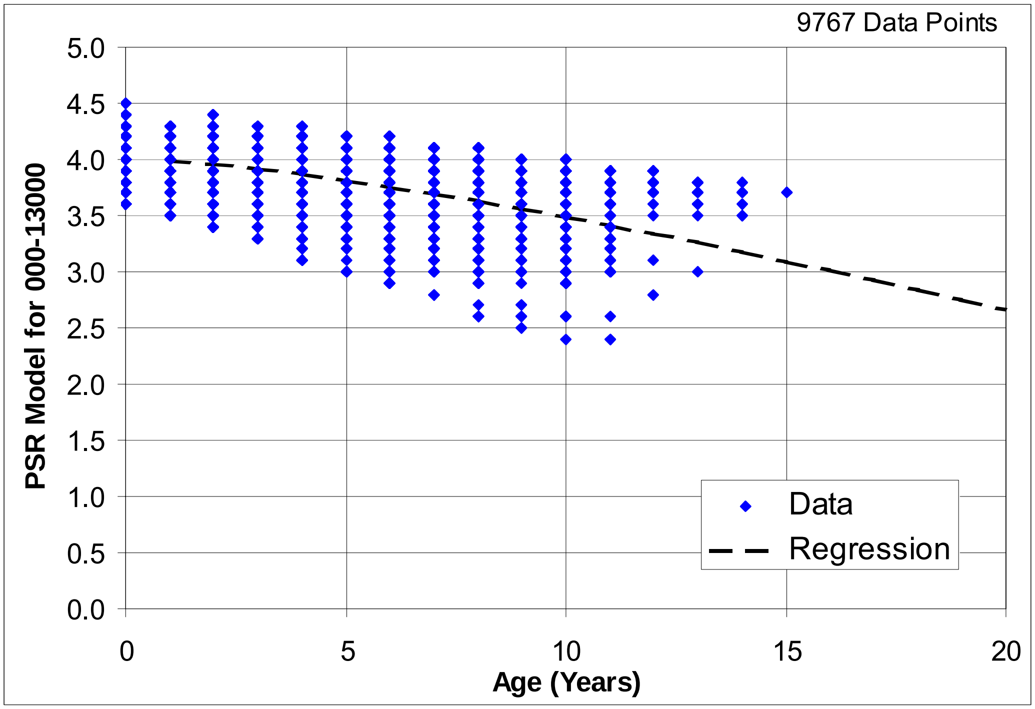

Figure 5.7: Interstate Historic Roughness Data in the Maintain Zone

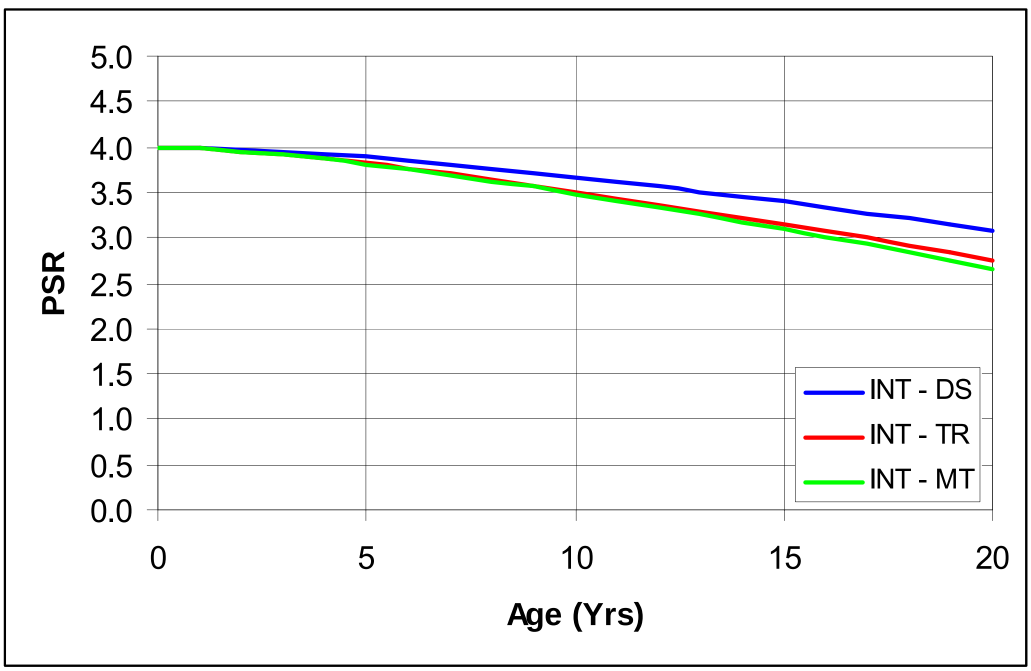

Figure 5.8: Regression Analysis Results for Interstate Highways by Environment Zone

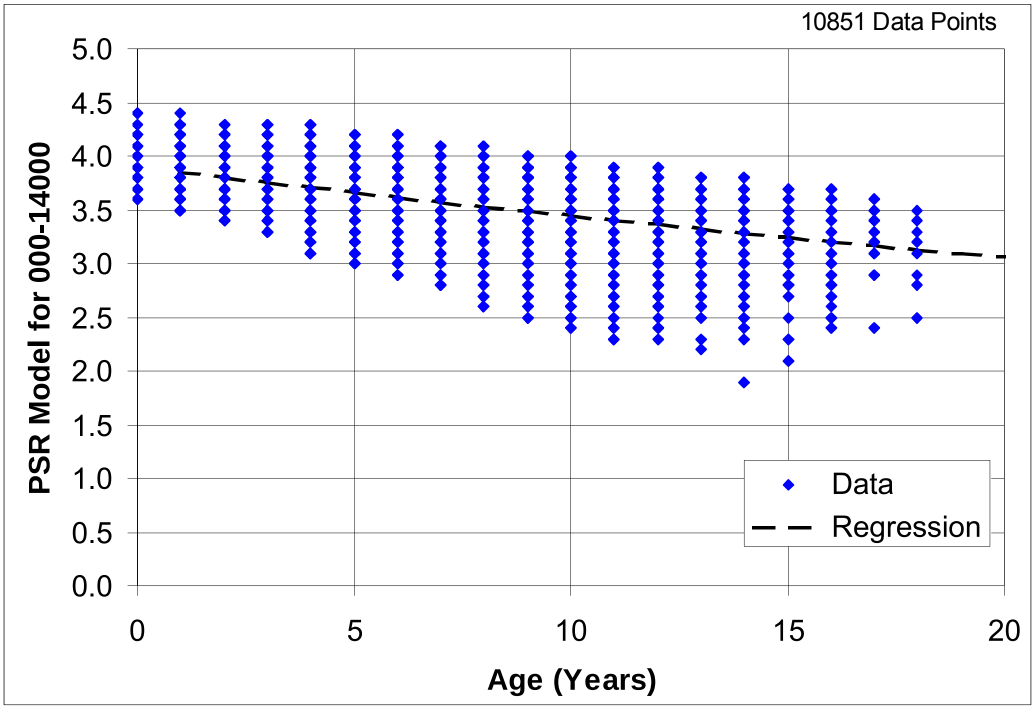

Figure 5.9: Non-Interstate Historic Roughness Data in the Desert Zone

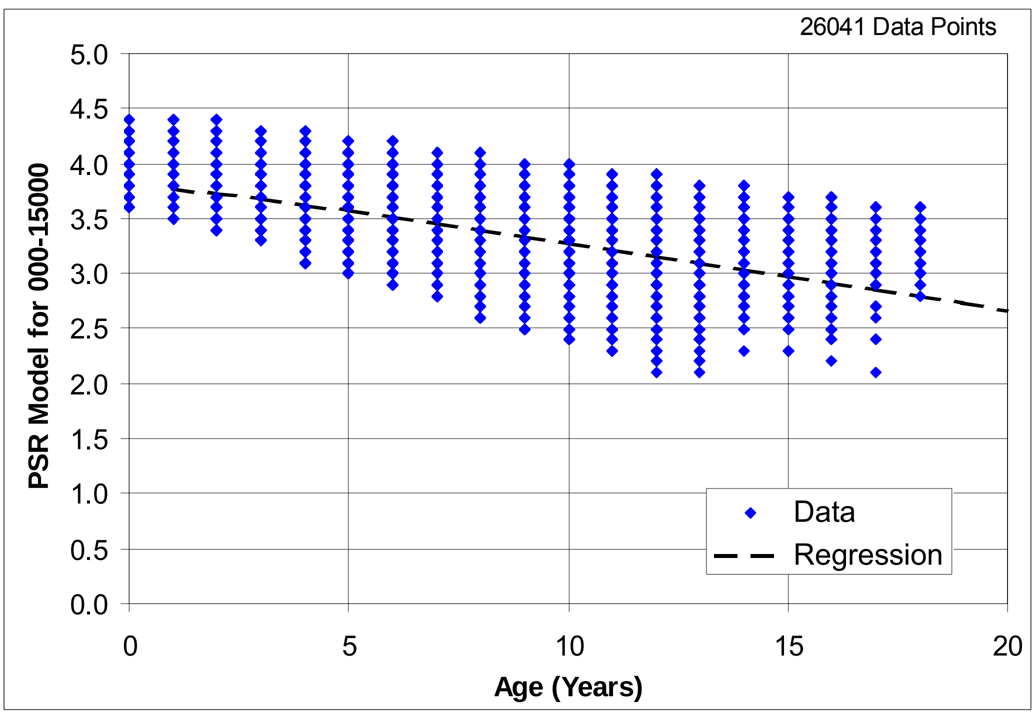

Figure 5.10: Non-Interstate Historic Roughness Data in the Transition Zone

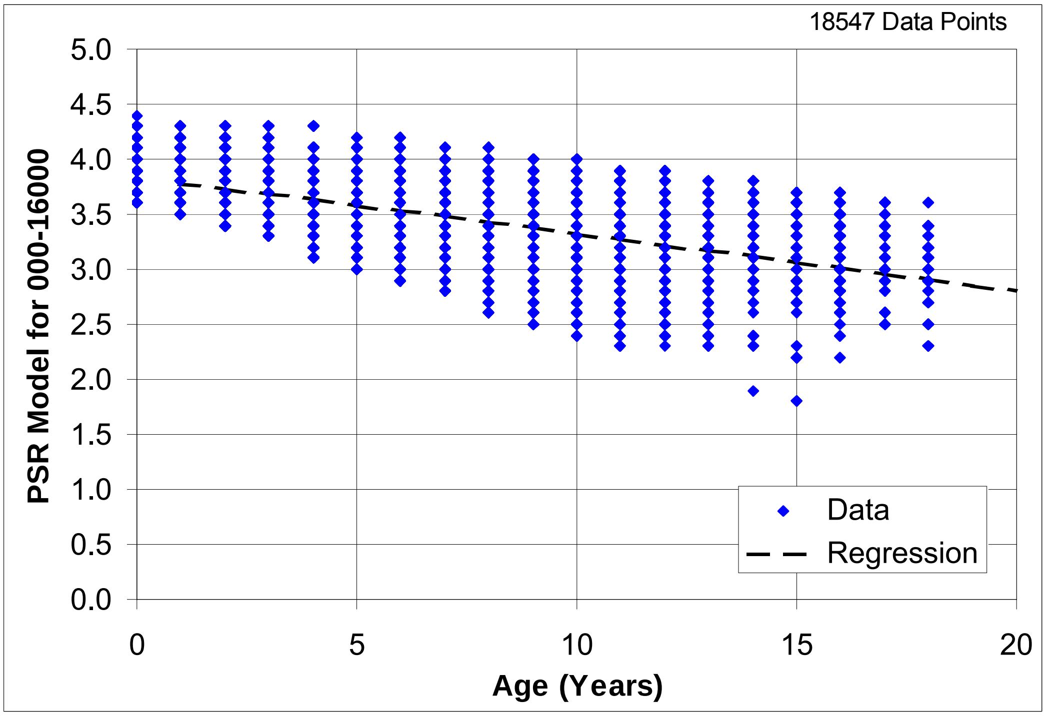

Figure 5.11: Non-Interstate Historic Roughness Data in the Mountain Zone

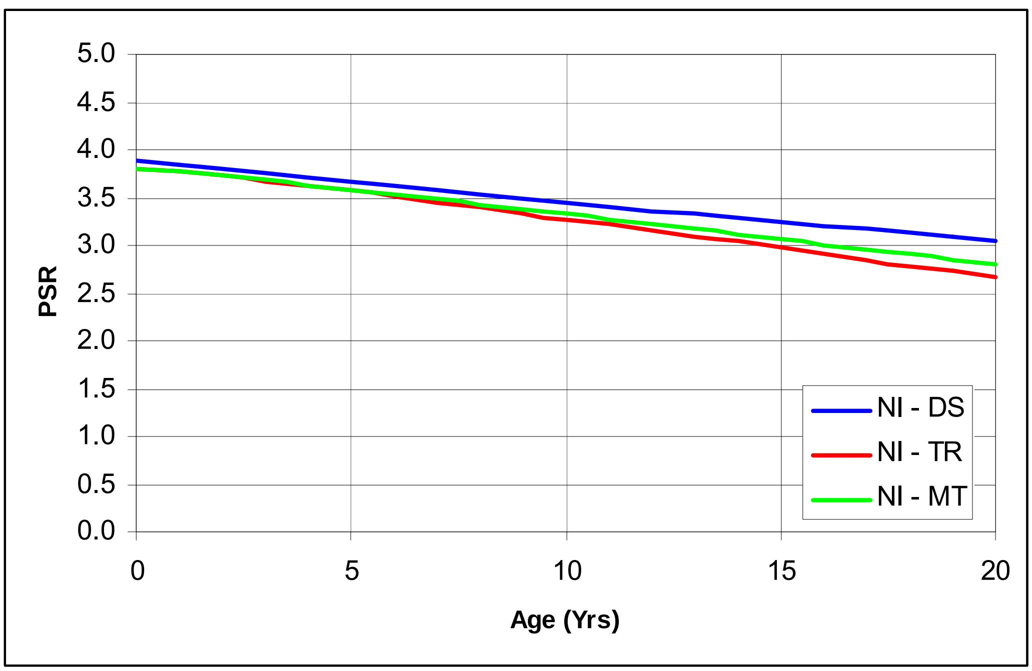

Figure 5.12: Regression Analysis for Non-Interstate Highways by Environment Zone

5.6.2.4 Available Historic Data

Historic data was extracted for each rehabilitation activity and sorted based on the functional class and the environment zone. It should be noted that only AC pavements were considered for regression analysis, because there was not enough data available for modeling for the other pavement types. Table 5.8 shows the number of historic data points available for regression sorted by functional class and environmental zone, before and after filtering outlier data, where number of data points after filtering is shown between parentheses. As can be noted from the table, the number of data points for each combination vary; and some combinations do not have any data.

Table 5.8: Historic Data Available for Regression

Rehabilitation Activity	Environment/Functional Class			
	Class 1	Class 2	Class 3	Class 4
201	2473 (1818)	1849 (1647)	2011 (1822)	3169 (2946)
202	88 (78)	2733 (2488)	253 (246)	1328 (1127)
206			651 (552)	2060 (1841)
211			623 (591)	1129 (1037)
212	2872 (2041)	2451 (1856)	81 (67)	184 (151)
213	4934 (3569)	10036 (7780)	405 (347)	338 (269)
214	11 (11)	1531 (1186)		346 (270)
215	2053 (1532)	2962 (2190)	103 (79)	300 (247)
216		200 (142)	783 (527)	916 (653)
217	72 (60)			
221	11 (11)	854 (601)	3442 (2358)	34308 (27005)
222	264 (148)	4056 (3354)	357 (287)	2042 (1587)
223	3663 (2504)	7617 (5898)	3268 (2872)	4839 (4305)
228	602 (535)	2974 (1968)	631 (480)	2505 (1562)
238	4399 (3114)	9189 (6885)	726 (481)	2425 (1844)
251	7 (7)	252 (162)		36 (32)
252				276 (190)
501	204 (173)	547 (520)	2135 (1678)	5777 (4811)

Note: Numbers shown between parentheses are available data points after filtering

5.6.3 Regression Analysis Approach

Non-linear regression analysis was carried out on filtered data to develop performance models for different rehabilitation activates. As mentioned earlier, a sigmoidal model was fitted to the data using the least squares approach to develop the required models. Some of the models were adjusted to account for the expected initial condition of the pavement sections immediately after rehabilitation or for the expected service life, as follows.

5.6.3.1 Initial Condition

The initial condition of the pavement immediately after specific rehabilitation activity (performance at age 0), or the coefficient O in the sigmoidal model, was generally determined by extrapolating the average performance in the first and second year of the pavement life. However, this initial condition had to be greater than or equal to the minimum initial condition based on experience for that particular activity/class combination. Table 5.9 shows the minimum required initial conditions.

Table 5.9: Minimum Initial Roughness Levels

<table>
<tr><th colspan="2" rowspan="2">Rehab Activity</th><th colspan="4">Environment/Functional Class</th></tr>
<tr><th>Class 1</th><th>Class 2</th><th>Class 3</th><th>Class 4</th></tr>
<tr><td colspan="2">Initial Construction / Reconstruction</td><td>4.7</td><td>4.7</td><td>4.5</td><td>4.5</td></tr>
<tr><td rowspan="2">Rehabilitation</td><td>No Milling</td><td>4.2</td><td>4.2</td><td>4.0</td><td>4.0</td></tr>
<tr><td>Milling</td><td>4.4</td><td>4.4</td><td>4.2</td><td>4.2</td></tr>
</table>

5.6.3.2 Pavement Service Life and Trigger Levels

The expected service lives of the different Maintenance and Rehabilitation activities were established based on ADOT's experience. The expected service lives of the activities are usually needed to asses the reasonableness of the models developed based on historical data and to adjust them if needed.

Also, the rehabilitation trigger levels or threshold levels were established based on discussions with ADOT's staff.

Table 5.10 shows the trigger levels for rehabilitation for different environment and functional classifications, in terms of both the IRI and PSR.

Table 5.10: Roughness Trigger Level for Rehabilitation

Trigger Level	Environment/Functional Class			
	Class 1	Class 2	Class 3	Class 4
IRI	75	75	90	90
PSR	3.75	3.75	3.55	3.55

5.6.4 PSR Performance Models

A complete set of prediction models was developed for the M&R activities shown in Table 5.11. Four models were developed for each activity, one model for each Environment/Functional Class combination.

Each cell in Table 5.11 shows the basis (or the source) of the model assigned to that treatment/class. There were four sources of the developed models, which were:

1. Models developed based on historical data with some minor adjustment for initial condition and/or service life. Cells with this type of model will have the assigned activity/class model (Adj).

2. Models developed by adopting another activity/class model, and modifying it because of lack of historical data. A cell with this type of model will have the assigned activity/class model plus (Mod).

3. Models developed by adopting another activity/class model, and modifying it because the models developed based on the historical data resulted in erroneous models. A cell with this type of model will have the assigned activity/class model plus (Mod).*

4. Models developed based on engineering judgment. A cell with this type of model will have Eng. Jud. in the cell.

Table 5.11: Development of PSR Models

ID	Description	Environment/Functional Class			
		Class 1	Class 2	Class 3	Class 4
201	Friction Course AC	**201-Class 1 (Adj)**	**201-Class 2 (Adj)**	**201-Class 3 (Adj)**	**201-Class 4 (Adj)**
202	Friction Course AR	202-Class 2 (Mod)	**202-Class 2 (Adj)**	**202-Class 3 (Adj)**	**202-Class 4 (Adj)**
203	Bit. Treat Surf 2 in	Eng. Jud.	Eng. Jud.	Eng. Jud.	Eng. Jud.
206	R&R Friction Course	206-Class 3 (Mod)	206-Class 4 (Mod)	**206-Class 3 (Adj)**	**206-Class 4 (Adj)**
207	R&R Rbr Friction Crs	206-Class 3 (Mod)	206-Class 4 (Mod)	206-Class 3 (Mod)	206-Class 4 (Mod)
211	Mill/Rep 2"AC+SC	211-Class 3 (Mod)	211-Class 4 (Mod)	**211-Class 3 (Adj)**	**211-Class 4 (Adj)**
212	Mill/Rep 1.5-3"AC+FR	**212-Class 1 (Adj)**	**212-Class 2 (Adj)**	212-Class 1 (Mod)	212-Class 2 (Mod)
213	Mill/Rep 1.5-3"AC+FC	**213-Class 1 (Adj)**	**213-Class 2 (Adj)**	**213-Class 3 (Adj)**	213-Class 3 (Mod)
214	Mill/Rep 1.5-3"AR+FR	212-Class 1 (Mod)*	212-Class 2 (Mod)*	212-Class 3 (Mod)	212-Class 4 (Mod)
215	Mill/Rep 3-5"AC+FR	**215-Class 1 (Adj)**	**215-Class 2 (Adj)**	215-Class 1 (Mod)	215-Class 2 (Mod)
216	Mill/Rep 3-5"AC+FC	216-Class 2 (Mod)	**216-Class 2 (Adj)**	**216-Class 3 (Adj)**	**216-Class 4 (Adj)**
217	Mill/Rep 3-5"AR+FR	215-Class 1 (Mod)*	215-Class 2 (Mod)	215-Class 3 (Mod)	215-Class 4 (Mod)
218	Mill/Rep 3-5"AC+SC	216-Class 1 (Mod)	216-Class 2 (Mod)	216-Class 3 (Mod)	216-Class 4 (Mod)
219	Mill/Rep >5"AC+FR	215-Class 1 (Mod)	215-Class 2 (Mod)	215-Class 3 (Mod)	215-Class 4 (Mod)

ID	Description	Environment/Functional Class			
		Class 1	Class 2	Class 3	Class 4
221	1.5-2.5"AC + SC	221-Class 2 (Mod)*	**221-Class 2 (Adj)**	**221-Class 3**	**221-Class 4**
222	1.5-3.0"AC + FR	222-Class 2 (Mod)*	**222-Class 2 (Adj)**	222-Class 4 (Mod)*	**222-Class 4 (Adj)**
223	1.5-3.0"AC + FC	**223-Class 1 (Adj)**	**223-Class 2 (Adj)**	**223-Class 3 (Adj)**	**223-Class 4 (Adj)**
224	2.5-3.5"AC + SC	223-Class 1 (Mod)	223-Class 2 (Mod)	223-Class 3 (Mod)	223-Class 4 (Mod)
225	2.5-3.5"AC + FR	223-Class 1 (Mod)	223-Class 2 (Mod)	223-Class 3 (Mod)	223-Class 4 (Mod)
226	2.5-3.5"AC + FC	223-Class 1 (Mod)	223-Class 2 (Mod)	223-Class 3 (Mod)	223-Class 4 (Mod)
227	3.0-5.0"AC + FR	228-Class 1 (Mod)	228-Class 2 (Mod)	228-Class 3 (Mod)	228-Class 4 (Mod)
228	3.0-5.0"AC + FC	**228-Class 1 (Adj)**	**228-Class 2 (Adj)**	**228-Class 3 (Adj)**	**228-Class 4 (Adj)**
229	3.0-5.0"AC + SC	228-Class 1 (Mod)	228-Class 2 (Mod)	228-Class 3 (Mod)	228-Class 4 (Mod)
231	RR1.5-3AC+1.5-3AC+FC	212-Class 1 (Mod)	212-Class 2 (Mod)	212-Class 3 (Mod)	212-Class 4 (Mod)
232	RR1.5-3AC+1.5-3AC+FR	212-Class 1 (Mod)	212-Class 2 (Mod)	212-Class 3 (Mod)	212-Class 4 (Mod)
233	RR1.5-3AC+1.5-3AR+FR	212-Class 1 (Mod)	212-Class 2 (Mod)	212-Class 3 (Mod)	212-Class 4 (Mod)
234	RR1.5-3AR+1.5-3AC+FR	212-Class 1 (Mod)	212-Class 2 (Mod)	212-Class 3 (Mod)	212-Class 4 (Mod)
235	RR1.5-3AR+1.5-3AR+FR	212-Class 1 (Mod)	212-Class 2 (Mod)	212-Class 3 (Mod)	212-Class 4 (Mod)
236	RR3-5"AC+1.5-3"AC+FC	228-Class 1 (Mod)	228-Class 2 (Mod)	228-Class 3 (Mod)	228-Class 4 (Mod)
237	RR3-5"AC+1.5-3"AC+FR	228-Class 1 (Mod)	228-Class 2 (Mod)	228-Class 3 (Mod)	228-Class 4 (Mod)
238	RR3-5"AC+1.5-3"AR+FR	**238-Class 1 (Adj)**	**238-Class 2 (Adj)**	**238-Class 3 (Adj)**	**238-Class 4 (Adj)**
239	RR3-5"AC+3-5"AC+FR	228-Class 1 (Mod)	228-Class 2 (Mod)	228-Class 3 (Mod)	228-Class 4 (Mod)
241	Overlay <=3" Recyc	Eng. Jud.	Eng. Jud.	Eng. Jud.	Eng. Jud.
242	Overlay 3-5" Recyc	Eng. Jud.	Eng. Jud.	Eng. Jud.	Eng. Jud.
251	RbrM+Overlay <=2.5	221-Class 1 (Mod)*	221-Class 2 (Mod)*	221-Class 3 (Mod)	221-Class 4 (Mod)*
252	RbrM+Overlay > 2.5	228-Class 1 (Mod)	228-Class 2 (Mod)	228-Class 3 (Mod)	228-Class 4 (Mod)*
253	RR1.5+RbrM+Ovrly3	238-Class 1 (Mod)	238-Class 2 (Mod)	238-Class 3 (Mod)	238-Class 4 (Mod)
261	1.5-2.5"AC	221-Class 1 (Mod)	221-Class 2 (Mod)	221-Class 3 (Mod)	221-Class 4 (Mod)
262	2.5-3.5"AC	223-Class 1 (Mod)	223-Class 2 (Mod)	223-Class 3 (Mod)	223-Class 4 (Mod)
301	Crack & Seat + AC Ovly	501-Class 2 (Mod)	501-Class 2 (Mod)	501-Class 3 (Mod)	501-Class 4 (Mod)
302	Jt & Slab Rep. + Ovly	501-Class 2 (Mod)	501-Class 2 (Mod)	501-Class 3 (Mod)	501-Class 4 (Mod)
401	Concrete Ovly	501-Class 2 (Mod)	501-Class 2 (Mod)	501-Class 3 (Mod)	501-Class 4 (Mod)
501	Orig. BIT Construction	501-Class 2 (Mod)	**501-Class 2 (Adj)**	**501-Class 3 (Adj)**	**501-Class 4 (Adj)**
502	Orig. BCB Construction	501-Class 2 (Mod)	501-Class 2 (Mod)	501-Class 3 (Mod)	501-Class 4 (Mod)
503	Orig. CON Construction	501-Class 2 (Mod)	501-Class 2 (Mod)	501-Class 3 (Mod)	501-Class 4 (Mod)
504	Orig. CRC Construction	501-Class 2 (Mod)	501-Class 2 (Mod)	501-Class 3 (Mod)	501-Class 4 (Mod)
505	Orig. CDP Construction	501-Class 2 (Mod)	501-Class 2 (Mod)	501-Class 3 (Mod)	501-Class 4 (Mod)
510	Reconstruct AC	501-Class 2 (Mod)	**501-Class 2 (Mod)**	**501-Class 3 (Mod)**	**501-Class 4 (Mod)**

Figure 5.13 shows an example of the models that were developed based on historic performance data. In the figure, the filtered historic data points, the regression model, and the adjusted model for that particular treatment are shown (ACFC for Non-Interstate routes in the Desert zone).

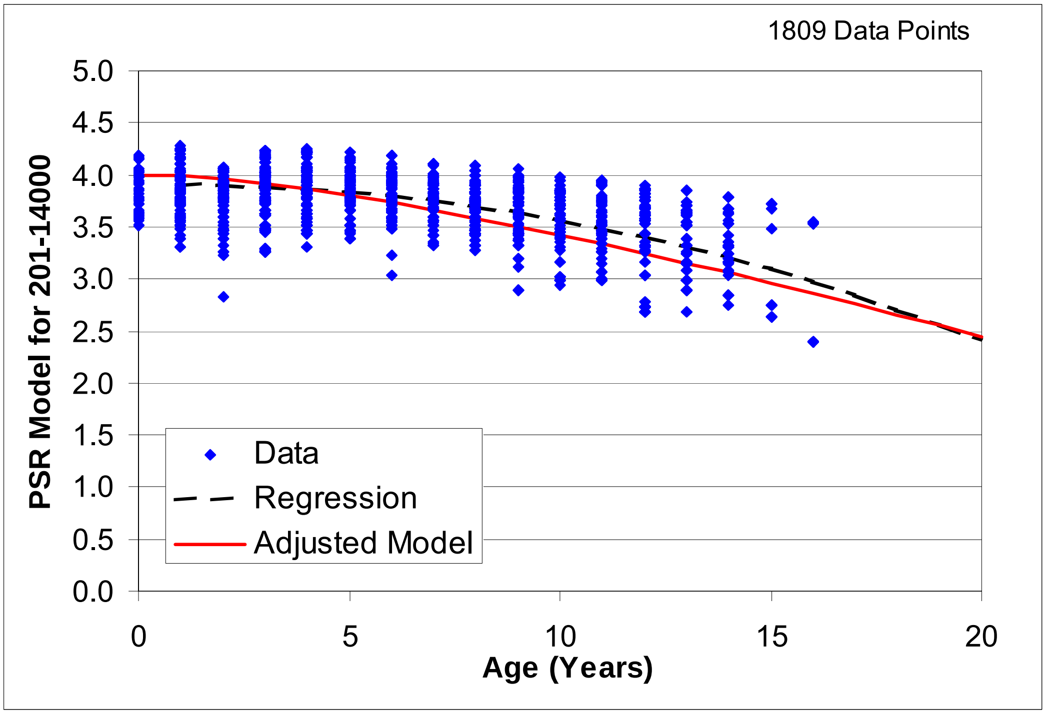

Figure 5.13: PSR Filtered Data and Model for 201- Class 3

5.7 DEVELOPMENT OF CRACKING DEFAULT PREDICTION MODELS

Similar to PSR, cracking default prediction models were developed based on the historic cracking data loaded to ADOT HPMA. Typically, site-specific models are developed during the analysis for each section, based on historical cracking data to predict the future performance of the current activity. However, in the absence of such data, or if the site-specific model does not meet the acceptance criteria, default models are used. Also, default models are used to predict the performance of future rehabilitation activities during the optimization analysis.

Non-linear regression analysis techniques were used to develop cracking prediction models for the rehabilitation activities where enough good historical data points are available. Some of the models were then adjusted to accommodate activities with insufficient historical data, or those resulting in erroneous models. In the following subsections, the development of default cracking models, based on ADOT historical performance data, is presented.

5.7.1 Cracking Model Form

ADOT HPMA utilizes an exponential model for distress prediction models. This form is used because it provides a suitable form of modeling distress progression, which usually starts from 0.0 and increases with time. The exponential model form used in ADOT HPMA has the following format:

$$C = e^{-\left(\frac{k}{Age}\right)^{B}} \quad \textbf{[5.9]}$$

Where C is the percentage cracking at a given Age, K and B are the model coefficients that define the model shape.

5.7.2 Historical Cracking Data

Historical cracking data was extracted using ADOT HPMA Feedback Module. Approximately, 90,000 historical cracking data points were available in the database. However, due to the general condition of ADOT's highway network and the distress data collection method utilized by ADOT, generally, the network has very low levels of cracking, where more than 80% of the historical cracking data is less than 5%. As an example, Figure 5.14 shows the distribution of percentage cracking data for ADOT's highway network for the year 2001, which is approximately 7400 data point. As can be noted, approximately 85% of the sections have percentage cracking less than 5%.

Cracking in pavements is usually attributed to either structural or environmental factors. In a PMS context, structural factors can be represented by the different rehabilitation activities, while environmental factors are represented in terms of the environmental zones. To identify whether any of these factors had an impact on the general performance of pavement sections in ADOT highway network, historical data was extracted based on activity type and environmental zone and analyzed.

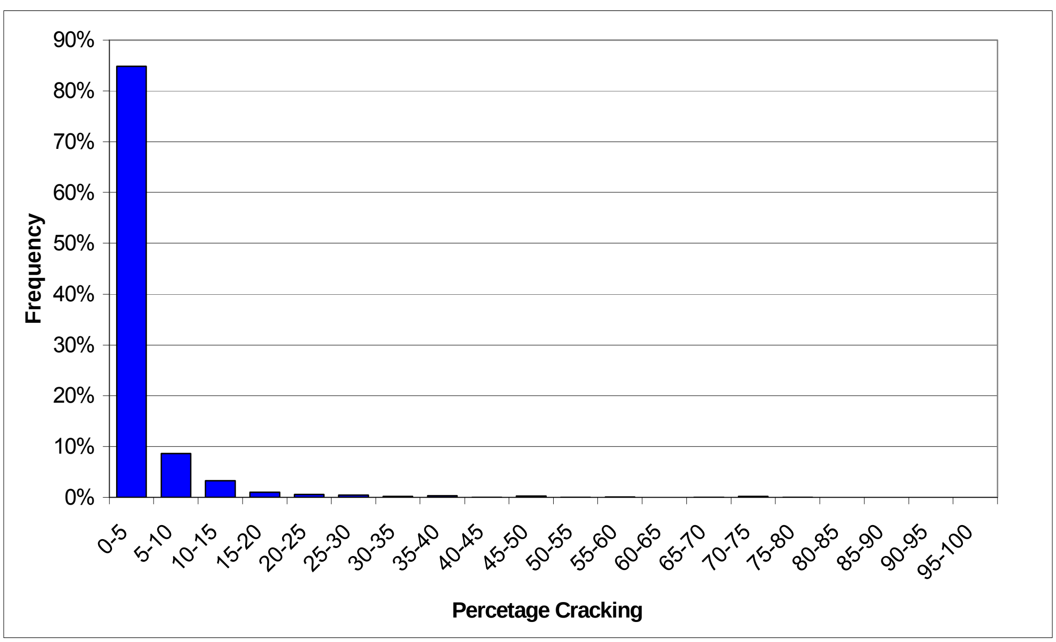

Figure 5.14: Distribution of Cracking Distress for ADOT Network in 2001

5.7.3 Development of Cracking Models

ADOT's historical data does not provide statistical significance to support development of different cracking prediction models for different activities and environmental zones. However, based on engineering judgment and using historical ADOT cracking data, distinct cracking prediction models were developed for different combinations of activities and environmental zones. The approach used in the development was to group the rehabilitation activities into a number of rehabilitation activity groups based on the activity type. Base prediction models are then developed for these groups using historic data through regression analysis. These base models are then manually adjusted to account for the differential performance among environmental zones.

The rehabilitation activities were grouped into 7 Cracking models; B1 though B7.

Table 5.12 shows these groups and the rehabilitation activities within each group. As can be noted from the table, each group includes a number of rehabilitation activities of expected similar behavior.

Cracking data was extracted for each group, and a non-linear regression analysis was performed on the data from each of these groups to develop the best-fit model that would result in the least sum of square error. For each group, the regression model was considered as a base model for this group, which will then be adjusted to account for the different environmental zones.

Figure 5.15 through Figure 5.21 show the regression results for each of these groups. As can be noted from these figures, the regression line that resulted in the least sum of squares of the error was rather low and resulted in an average percentage cracking between 5% and 10% after 15 years of service.

Table 5.12: Cracking Groups and Corresponding Rehabilitation Activities

Cracking Model Group	Group Description	Activity ID	Activity Name
B1	Remove-and-Replace thin Conventional AC Overlay	211	Mill/Rep 2"AC+SC
		212	Mill/Rep 1.5-3"AC+FR
		213	Mill/Rep 1.5-3"AC+FC
		231	RR1.5-3AC+1.5-3AC+FC
		232	RR1.5-3AC+1.5-3AC+FR
		234	RR1.5-3AR+1.5-3AC+FR
B2	Remove-and-Replace thin Rubberized AC Overlay	214	Mill/Rep 1.5-3"AR+FR
		233	RR1.5-3AC+1.5-3AR+FR
		235	RR1.5-3AR+1.5-3AR+FR
B3	Remove-and-Replace thick Conventional AC Overlay	215	Mill/Rep 3-5"AC+FR
		216	Mill/Rep 3-5"AC+FC
		217	Mill/Rep 3-5"AR+FR
		218	Mill/Rep 3-5"AC+SC
		219	Mill/Rep >5"AC+FR
		236	RR3-5"AC+1.5-3"AC+FC
		237	RR3-5"AC+1.5-3"AC+FR
B4	Surface treatments and thin Conventional AC Overlay	201	Friction Course AC
		202	Friction Course AR
		203	Bit. Treat Surf 2 in
		206	R&R Friction Course
		207	R&R Rbr Friction Crs
		221	1.5-2.5"AC + SC
		222	1.5-3.0"AC + FR
		223	1.5-3.0"AC + FC
		224	2.5-3.5"AC + SC
		225	2.5-3.5"AC + FR
		226	2.5-3.5"AC + FC
		241	Overlay <=3" Recyc
		242	Overlay 3-5" Recyc
		251	RbrM+Overlay <=2.5
		252	RbrM+Overlay > 2.5
		253	RR1.5+RbrM+Ovrly3
		261	1.5-2.5"AC
		262	2.5-3.5"AC
B5	Thick Conventional AC Overlay	227	3.0-5.0"AC + FR
		228	3.0-5.0"AC + FC
		229	3.0-5.0"AC + SC
B6	Thick Rubberized AC Overlay	238	RR3-5"AC+1.5-3"AR+FR
B7	Reconstruction Activities	239	RR3-5"AC+3-5"AC+FR
		501	Orig. BIT Construction
		510	Reconstruct AC

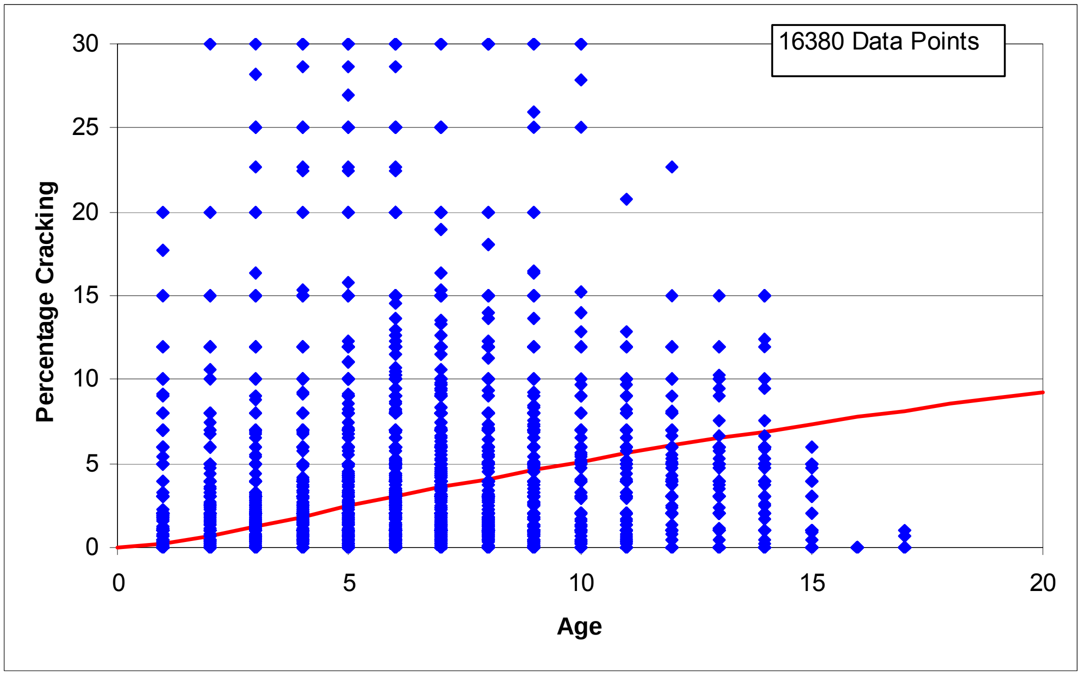

Figure 5.15: B1 Cracking Group Regression Data

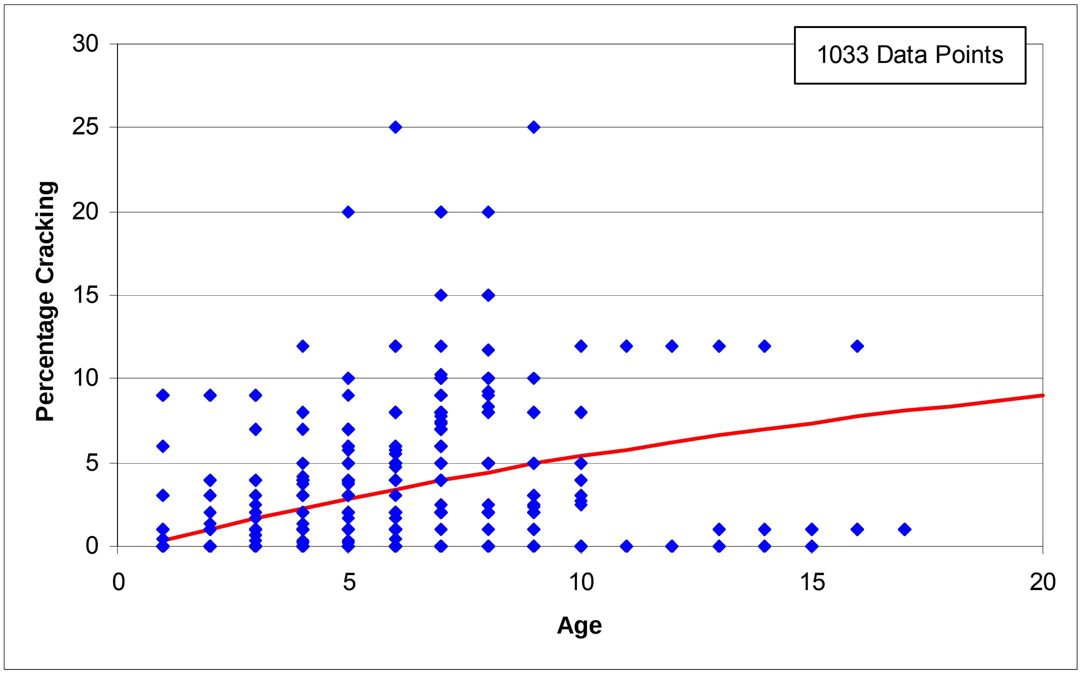

Figure 5.16: B2 Cracking Group Regression Data

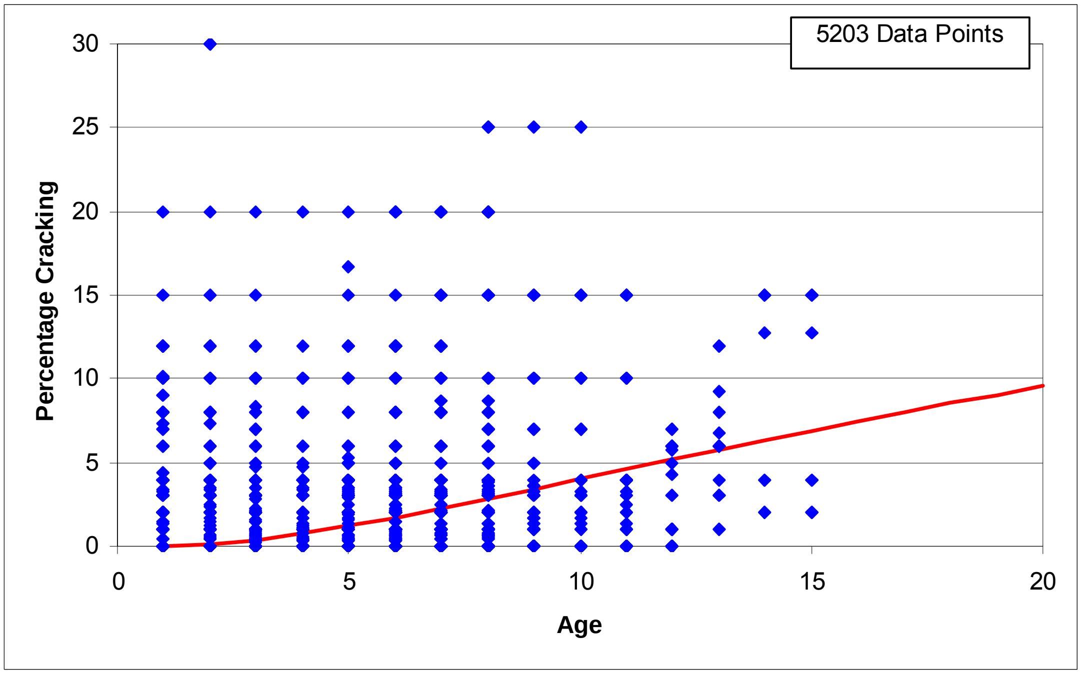

Figure 5.17: B3 Cracking Group Regression Data

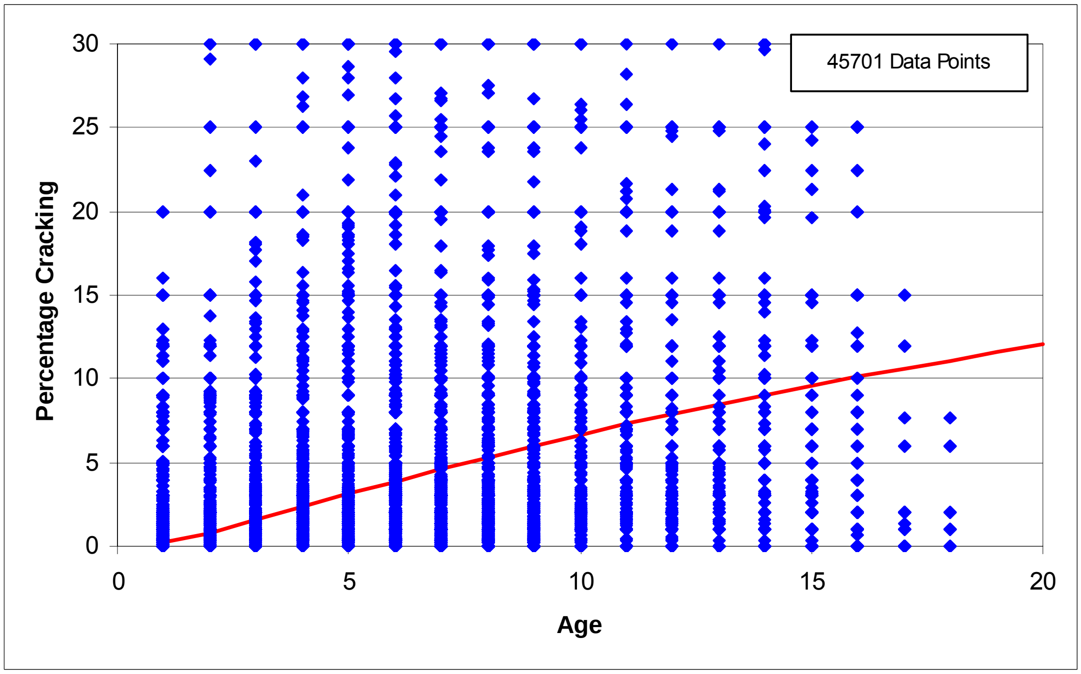

Figure 5.18: B4 Cracking Group Regression Data

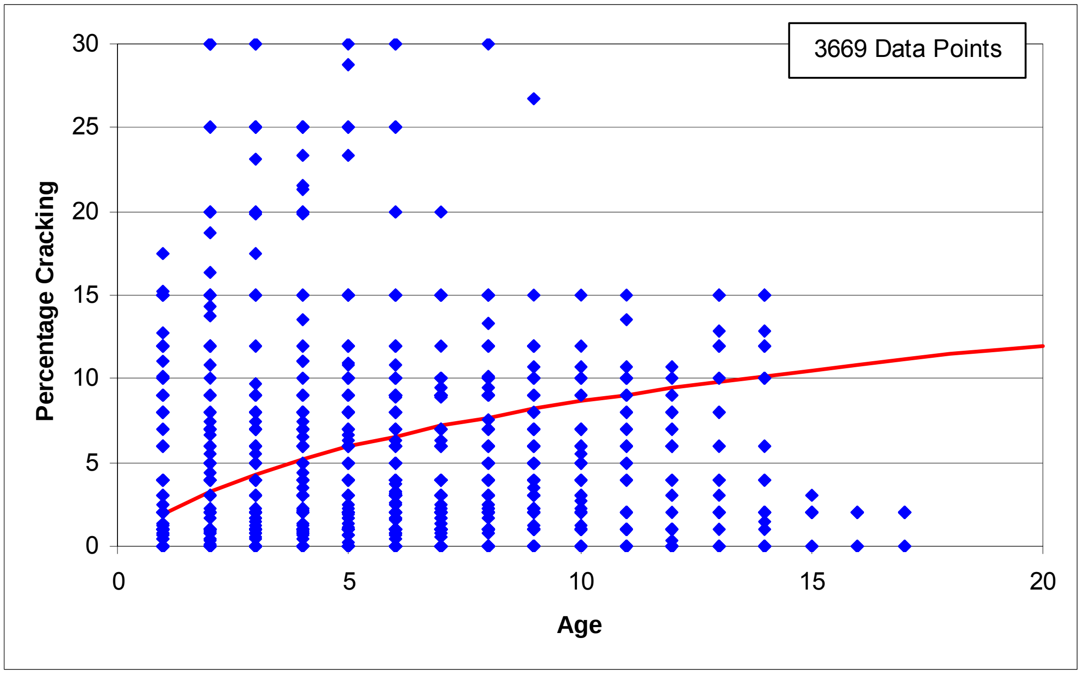

Figure 5.19: B5 Cracking Group Regression Data

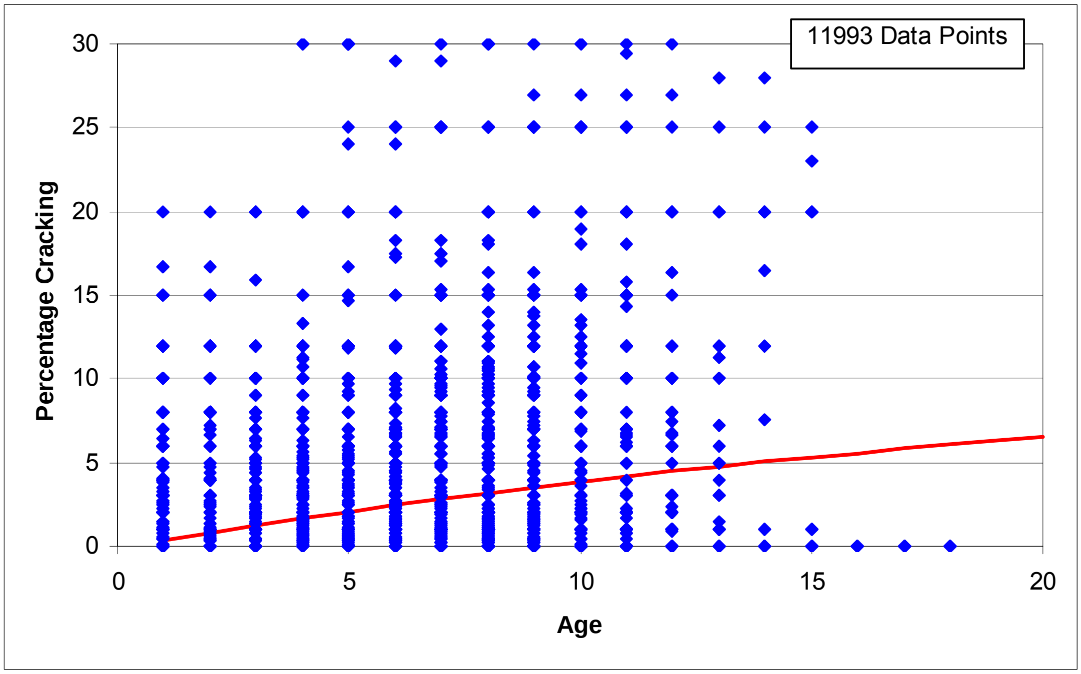

Figure 5.20: B6 Cracking Group Regression Data

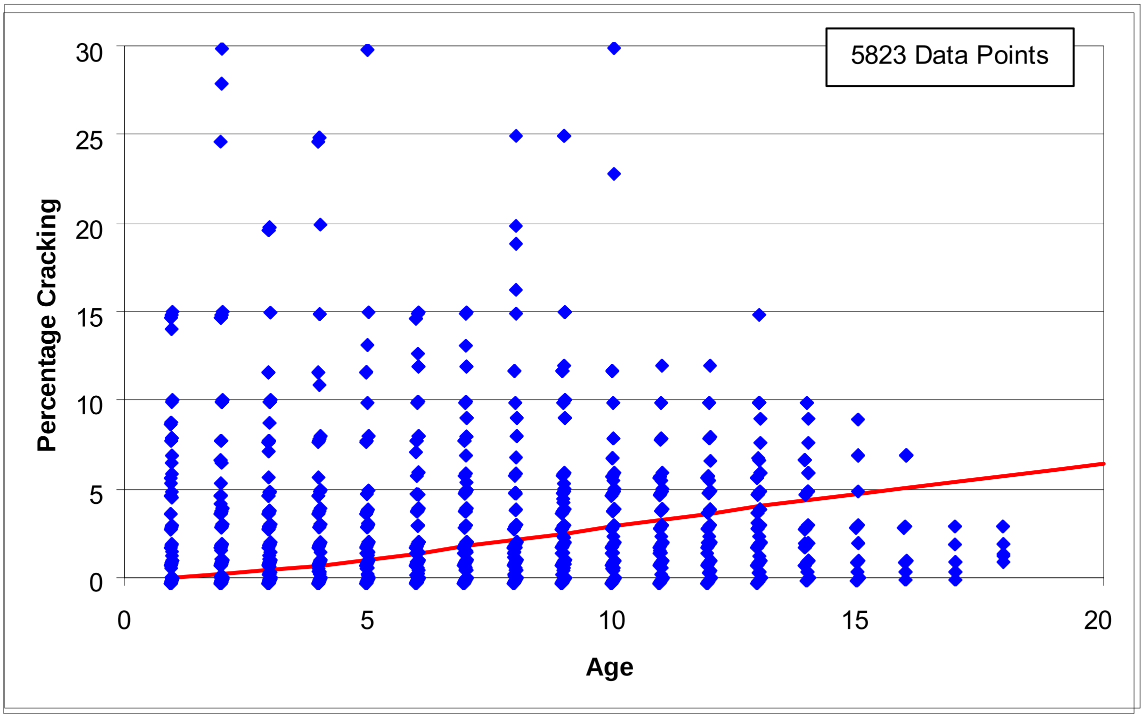

Figure 5.21: B7 Cracking Group Regression Data

5.7.4 Final Set of Cracking Prediction Models

The base cracking models were adjusted to account for the differences in the expected performance between the different environmental zones. The adjustment was performed by maintaining the "shape" of the prediction model, but adjusting the service life produced by the model in different environmental zones. The service life was assumed to be the age at which the pavement section reaches a cracking level of 5%. The service life of sections located in the Desert zone was assumed to be longer that those located in the Transition zone, which is in turn longer than the service life of section in the Mountain zone.

The differential performance between Interstate and Non-Interstate routes was not accounted for due to the fact that the cracking levels for all highway sections was relatively low, such that capturing this differential performance was not practical based on the available data.

Table 5.13 shows the expected service life for each group of activities, based on a trigger level of 5%. As can be noted from the table, the base model developed through regression analysis, was considered to represent the pavement sections in the Transition zone. The model was adjusted, such that the service life in the Desert zone is approximately 2 years longer than that of the base model, while the service life in the Mountain zone was 2 years shorter that than that of the base model.

Table 5.13: Approximate Service Life In Years for Cracking Prediction Models

Cracking Model Group	Environmental Zone		
	Desert	Transition	Mountain
B1	11.5	9.4	7.6
B2	11.2	9.2	7.3
B3	13.6	11.7	9.9
B4	9.3	7.5	5.9
B5	12.7	10.5	8.6
B6	14.8	12.5	10.3
B7	17.8	15.8	13.8

5.8 APPROACH FOR MAINTENANCE INTEGRATION INTO PMS

One of the main objectives of this project is to expand the use of the pavement management tools to support the maintenance functions. This objective is achieved using ADOT HPMA by incorporating the corrective maintenance and the preventive maintenance activities into the overall framework of the Maintenance and Rehabilitation (M&R) analysis and optimization analysis. Figure 5.22 depicts the analysis approach that can be used for the development of ADOT's pavement preservation program.

The following subsections provide a brief description of this approach as shown in Figure 5.22, together with an overview of some of the analysis functions in ADOT HPMA. It should be noted however, that this approach was developed based on the following assumptions:

- The Corrective Maintenance (CM) program is a one-year program, where the section selection is based on the current condition data. Also, the impact of the CM activities on future performance is negligible
- The Preventive Maintenance (PM) and Rehabilitation (Rehab) programs are multi-year programs, where the section selection is based on the current and predicted performance data
- The impact PM and Rehab on pavement future performance is accounted for by using specific performance prediction models
- Budget constraints are considered in the section selection process and candidate sections compete against each other, based on cost-effectiveness

5.8.1 Creating Analysis Sections and Predicting Pavement Performance

Using HPMA Dynamic Sectioning Module, the entire highway network is divided into a set of analysis sections. These sections can either be manually defined and loaded as overrides or defined through dynamic sectioning using user-defined criteria (Box 2 in Figure 5.22).

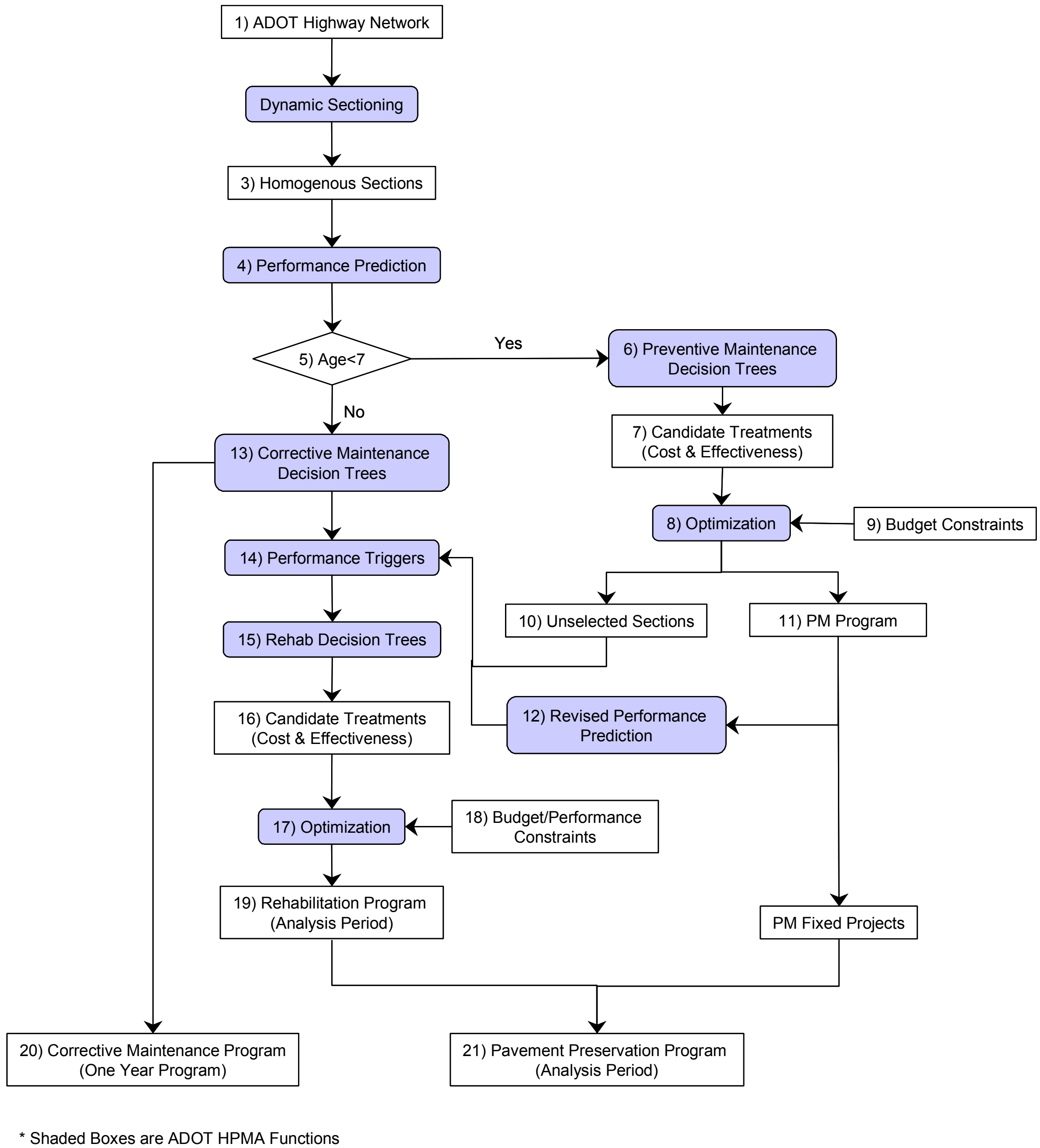

Figure 5.22: Proposed Analysis Approach

For each homogeneous section, the future condition, in terms of roughness and surface distress, is predicted for each year of the analysis period using site-specific models or default prediction models.

In case a default prediction model is used, the selected model is adjusted to fit the latest historic measured data points by shifting the model horizontally such that the latest known performance data point falls on the default model, as shown in Figure 5.23. Horizontally shifting the curve ensures that the deterioration rate at a specific

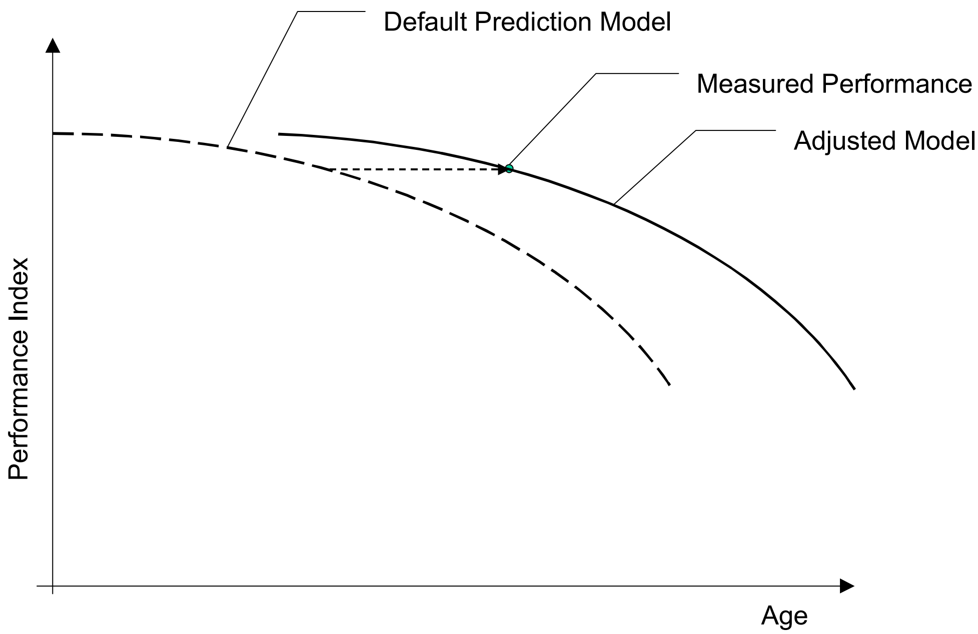

Figure 5.23: Shifting of Default Index Prediction Models

performance level, which is the latest measured data, is constant regardless of the actual construction date

Sections are candidates for PM if their age is equal to or less than 7 years (Box 5 in Figure 5.22). All sections that are not candidates for PM are candidates for CM, whether they are triggered for Rehab or not (Box 13 in Figure 5.22). However, sections are candidate for Rehab only if their predicted performance hits the trigger levels any time during the analysis period (Box 14 in Figure 5.22)

5.8.2 Treatment Selection

Sections that are candidates for PM will go through the appropriate PM decision tree to identify the candidate treatments. It should be noted that this process will be repeated for every year in the analysis period, as long as the section still meets the PM criterion (age less than or equal to 7 years). The final outcome of this step is a list of sections that are candidates for PM and the candidate treatments for each section for each year of the analysis period (Boxes 6, 7 & 8 in Figure 5.22)

Budget constraints will be implemented on the resulting feasible treatments to select the most cost-effective PM program that meets the budget constraints. The predicted performance of the sections included in the PM program will be revised to account for the positive impact of PM. These sections will be considered for Rehab if their revised performance is triggered for rehabilitation during the analysis period (Boxes 11 & 12 in Figure 5.22). The sections that are candidates for PM and not selected in the PM program will be checked with respect to rehabilitation based on their predicted performance (Box 10 in Figure 5.22)

All sections that are not selected for PM will go through the appropriate CM decision tree to identify the corrective maintenance treatments for these sections (Box 13 in Figure 5.22). However, selecting a corrective maintenance activity for any section will have no effect on its future performance and it will still be considered for Rehab. Sections that will be considered for Rehab are:

- The sections that are not candidates for PM and triggered for Rehab based on their predicted performance and the appropriate trigger level (Box 14 in Figure 5.22)
- Sections that are candidates for PM, but not selected in the PM program, and triggered for Rehab based on their predicted performance and the appropriate trigger level (Box 10 in Figure 5.22)
- Sections that are in the PM program and triggered for Rehab based on their revised predicted performance and the appropriate trigger level (Box 10 in Figure 5.22)

These sections will go through the appropriate Rehab decision tree to identify the candidate treatments. It should be noted that this process is repeated for every year in the analysis period. The final outcome of this step is a list of sections that are triggered for Rehab in any of the analysis years and the candidate treatments for each section for each year of the analysis period. For each section/treatment/year combination, the cost, effectiveness, and cost-effectiveness is calculated (Boxes 15, 16 & 17 in Figure 5.22).

The cost is calculated using the unit costs set in Function 6-2-1 in ADOT HPMA, as the product of the area of the section and the unit cost for the selected M&R activity. The Effectiveness is calculated using the following equation:

$$\text{Effectiveness} = \text{Weighting} * \text{SectionsArea} * \text{Area-Under-The-Curve} \qquad \textbf{[5.10]}$$

where the Weighting is a factor defined through Function 6-2-2 in ADOT HPMA to provide a priority rating to the different sections. Currently, the weighting factor is a function of AADT. The Section Area is the surface area of the pavement section. The Area-Under-The-Curve is the area under the rehabilitation curve and above the do-nothing curve or the minimum defined performance level; whichever is greater, as shown in Figure 5.24.

The cost-effectiveness (CE) of a specific activity within the section is the ratio between the effectiveness and the cost. The higher the CE of a specific project, the more "benefit" to the overall network performance. CE is used in the optimization analysis to select the more "beneficial" project and to prioritize the sections during the selection process.

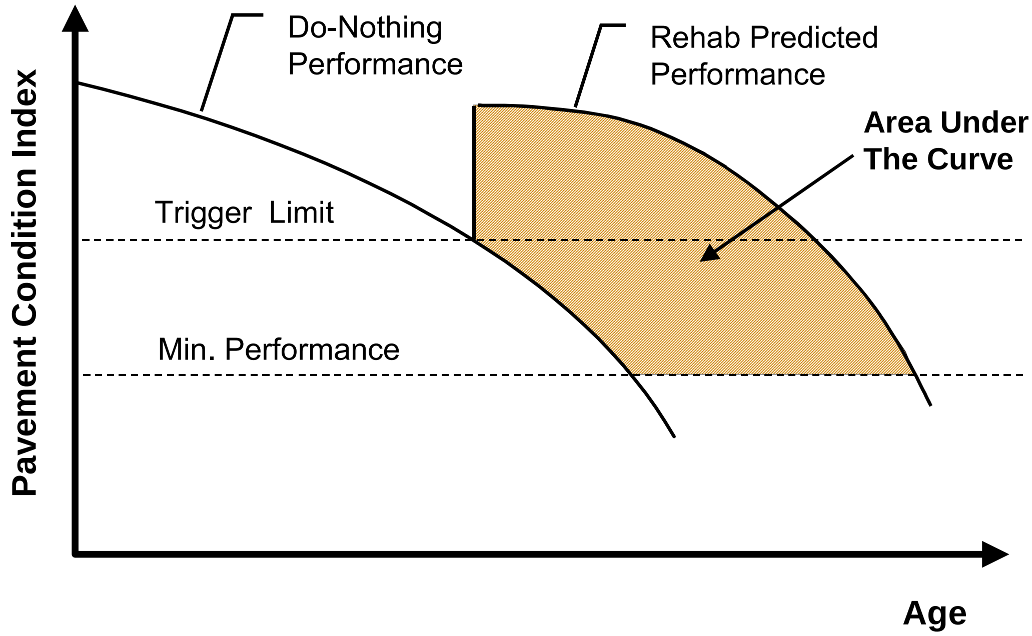

Figure 5.24: Rehabiliation Activities Effectiveness – Area Under the Curve

5.8.3 Final Program

The constraints are set for the analysis using either the budget constraints (-1 for unlimited budget), or the performance constraints. Budget constraints are used in the case of limited budgets, while the performance constraints are used when unlimited budget is available to achieve a specific level of performance. Both constraints can be used within the same optimization run, but should not be used within the same year. The budget allocation is usually based on the CE, which means that the budget is allocated to achieve the highest possible performance for the network (Box 18 in Figure 5.22). The final program will consist of:

- CM Program, as explained above (Box 20 in Figure 5.22)
- Pavement Preservation Program (Box 21 in Figure 5.22), which includes both the PM Program (Box 12 in Figure 5.22) and the Rehab Program (Box 19 in Figure 5.22).

5.9 DECISION TREES

The Decision Trees (DT) are one of the critical components of ADOT HPMA that can significantly affect the analysis results. DTs are used to model the logical approach for selecting the feasible M&R alternatives for each section during the analysis, based on the section conditions and performance. ADOT HPMA has three types of DT's, which are the Preventive Maintenance (PM), Corrective Maintenance (CM), and Maintenance and Rehabilitation (M&R) decision trees.

Decision trees should be developed for each combination of pavement conditions, such as pavement type, environmental zone, etc. However, based on preliminary analysis and discussions with ADOT personnel, it was decided to develop identical DT's for all environmental zones, and account for variation in the service life of the pavements due to the variation of the environmental zones in the pavement performance prediction models. This approach has been described earlier in the development of the PSR prediction models and the cracking prediction models. Table 5.14 shows the variables considered in the development of the decision trees and the levels of these variables. As can be noted from the table, the total number of required DT's is 12 (3 types * 2 Pavement types * 2 functional classes)

Table 5.14: Variables Considered for the Decision Trees

Variable	Levels
Tree Type	▪ Preventive Maintenance (PM) ▪ Corrective Maintenance (CM) ▪ Rehabilitation (M&R)
Pavement Type	▪ AC Pavement ▪ PCC Pavement
Functional Class	▪ Interstate Highways ▪ Non-Interstate Routes

5.9.1 Preventive Maintenance Decision Trees

Preventive maintenance decision trees are designed to address pavement sections in relatively "good" surface condition, and in order to maintain such condition.

5.9.1.1 Preventive Maintenance Decision Trees for AC Pavements

Preventive maintenance decision trees for AC pavements are developed for both Interstate and Non-Interstate routes. These trees were developed based on discussions with ADOT staff, and then modified, accordingly after ADOT final revisions, to reflect actual treatments used for pavement maintenance. The decision trees for Interstate and Non-Interstate routes are generally similar, with the exception of the final treatments. On Interstate routes, rubberized friction course or regular friction course are typically used, whereas for Non-Interstate routes, regular friction course or seal coats are used. Figure 5.25 and Figure 5.26 show the preventive maintenance decision trees for the Interstate and Non-Interstate routes, respectively. Table 5.15 describes the end nodes for these trees.

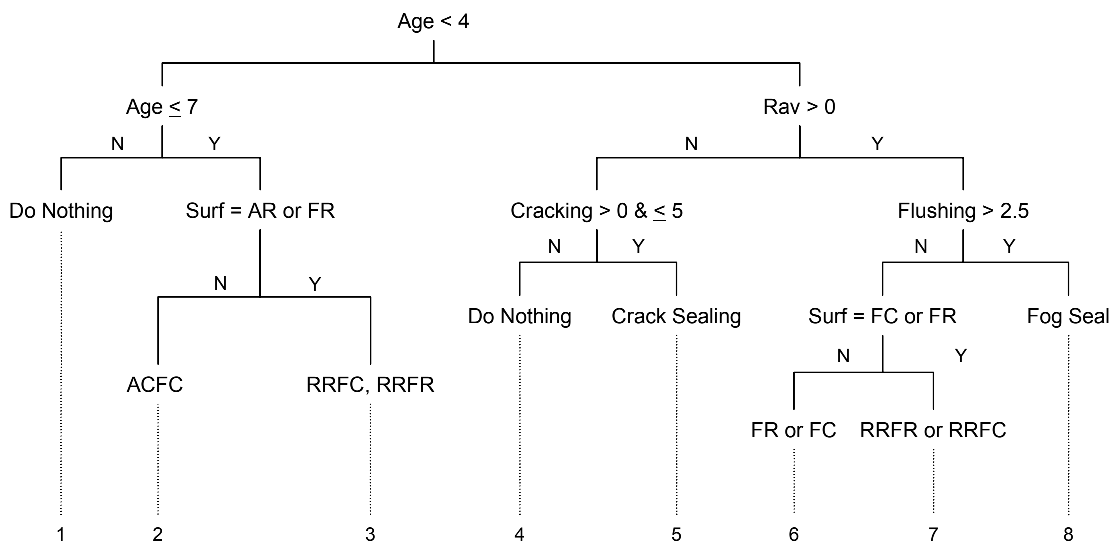

Figure 5.25: Preventive Maintenance DT for Interstate Routes AC Pavements

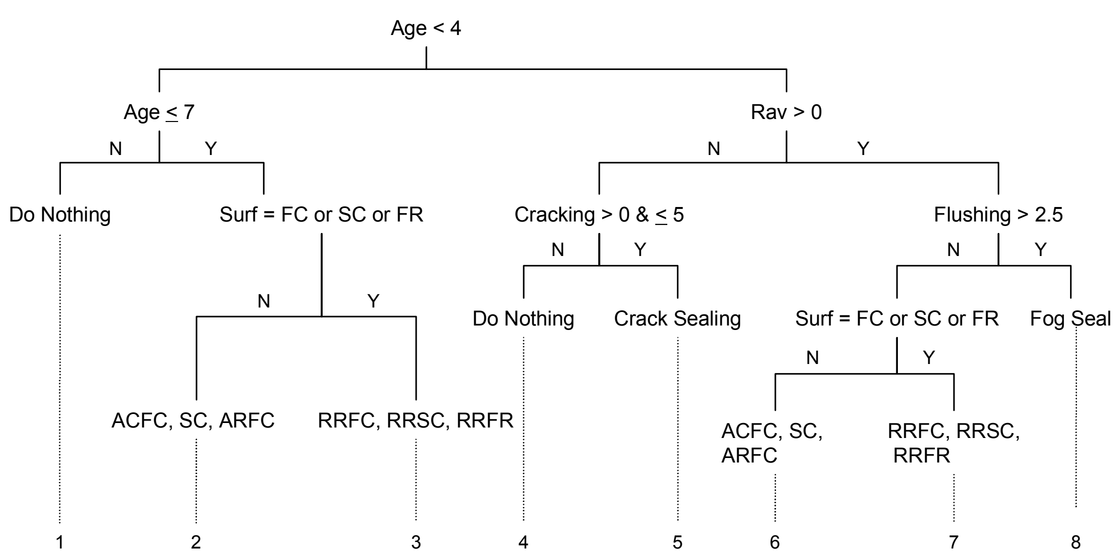

Figure 5.26: Preventive Maintenance DT for Non-Interstate Routes AC Pavements

Table 5.15: Description of Decision Tree End Nodes for Preventive Maintenance DT

Node	Description	Possible Pavement Condition	Recommendation
1	Pavement is already more than 7 years old and is not a candidate for preventive maintenance		Do not perform preventive maintenance
2	Pavement is between 4 and 7 years old with no friction course (seal coat)		Add a friction course (seal coat)
3	Pavement is between 4 and 7 years with/without a friction course or seal coat	Friction course or seal coat may have worn off	Use a friction course or seal coat to reduce noise
4	Pavement is relatively new, with no raveling and no cracking (cracking >5% will trigger rehabilitation)	Pavement in good condition	Do Nothing
5	Pavement is relatively new, with no raveling and some cracking	Minor surface cracking	Seal the cracks
6	Pavement is relatively new, with some raveling and flushing, and a missing friction course	Both raveling and flushing issues	Add a friction course
7	Pavement is relatively new, with some raveling and flushing, and a missing friction course	Both raveling and flushing issues	Remove and replace thin surface layer
8	Pavement is relatively new, with some raveling and no flushing	Raveling problem	Use a fog seal

5.9.1.2 Preventive Maintenance Decision Trees for PCC Pavements

PCC pavement sections in Arizona are predominantly located in Interstate routes, and Non-Interstate PCC sections are limited. Subsequently, only one PM decision tree for PCC pavements is developed, which would be applicable for PCC sections on both Interstate and Non-Interstate routes. The PM decision tree for PCC pavements mainly addresses pavements in relatively "good" condition. Deteriorated sections are addressed in CM or M&R trees. Figure 5.27 shows the preventive maintenance DT for PCC pavements, and Table 5.16 describes the end nodes for this DT.

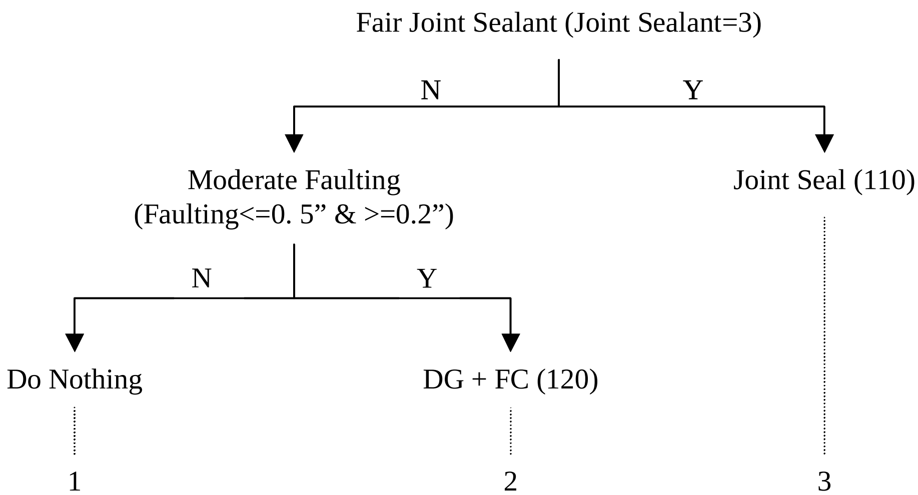

Figure 5.27: Preventive Maintenance DT for PCC Pavements

Table 5.16: End Nodes for PCC Pavements Preventive Maintenance Decision Tree

Node	Description	Possible Pavement Condition	Recommendation
1	Joint sealants are in good condition, and only minor faulting may be present	Pavement in good condition	Do Nothing
2	The joint sealants are in good condition, but moderate faulting exists	Moderate Faulting	Grind the pavement surface and add a friction course
3	Joint sealants are starting to deteriorate	Fair Sealants	Seal deteriorating joints

5.9.2 Corrective Maintenance Decision Trees

Corrective maintenance decision trees are designed to address localized pavement distresses over a one-year programming period. Corrective maintenance decision trees are typically based on the presence of individual distresses and they involve interactive updating of the maintenance treatments, unit costs, and the decision parameters used in selecting maintenance treatments. This involves an activity hierarchy, which assigns a hierarchy of general maintenance treatments.

A hierarchy defines which of competing treatments will be selected. For example, if the distresses evident on a section result in selection of both crack filling + seal coat for one type of distress, and seal coat for another type, then in this case, the hierarchy could be set to select the crack filling + seal coat only. The G - M activity interaction option in the HPMA defines the general maintenance activity hierarchy. For each general maintenance activity, local (M) activities can be included or excluded. For example, if a seal coat were selected, then crack filling would be excluded/included from the treatment plan. For crack filling + seal coat, crack filling may be an included activity prior to the seal coat to slow down crack propagation.

5.9.2.1 Corrective Maintenance Decision Trees for AC Pavements

Through discussions with ADOT staff and based on the historic distress data in ADOT database, corrective maintenance decision trees for AC pavements were developed for three types of surface distresses, which are cracking, flushing, and potholes. Figure 5.28 and Figure 5.29 show these trees for AC pavements on Interstate and Non-Interstate routes, respectively. As can be noted, the CM trees are a group of individual trees each based on a specific distress type. Also, the trees for Interstate and Non-Interstate routes are similar, with the exception of the final treatment.

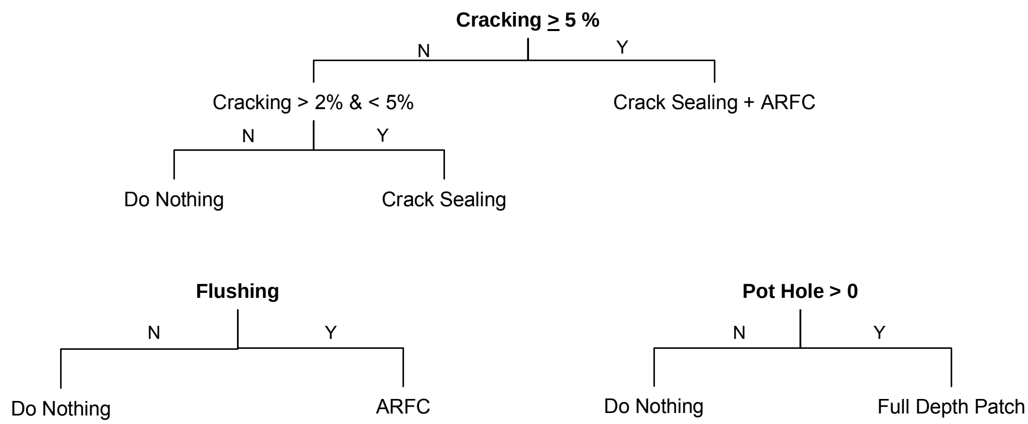

Figure 5.28: Corrective Maintenance DT for AC Pavements on Interstate Routes

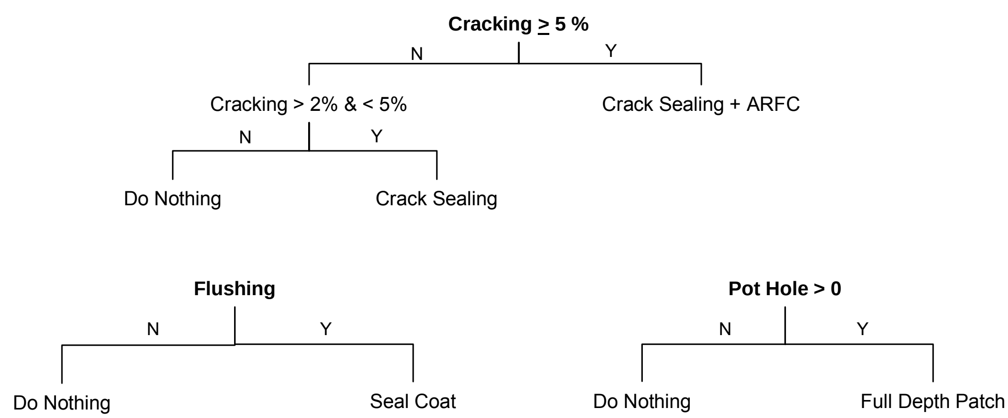

Figure 5.29: Corrective Maintenance DT for AC Pavements on Non-Interstate Routes

5.9.2.2 Corrective Maintenance Decision Trees for PCC Pavements

Through discussions with ADOT staff, corrective maintenance decision trees for PCC pavements were developed for four types of surface distresses, which are spalling, joint sealant defects, faulting, and poor load transfer. Figure 5.30 shows the CM decision for PCC pavements. Again, the CM trees are a group of individual trees each based on a specific distress type. These trees apply to both Interstate and Non-Interstate routes.

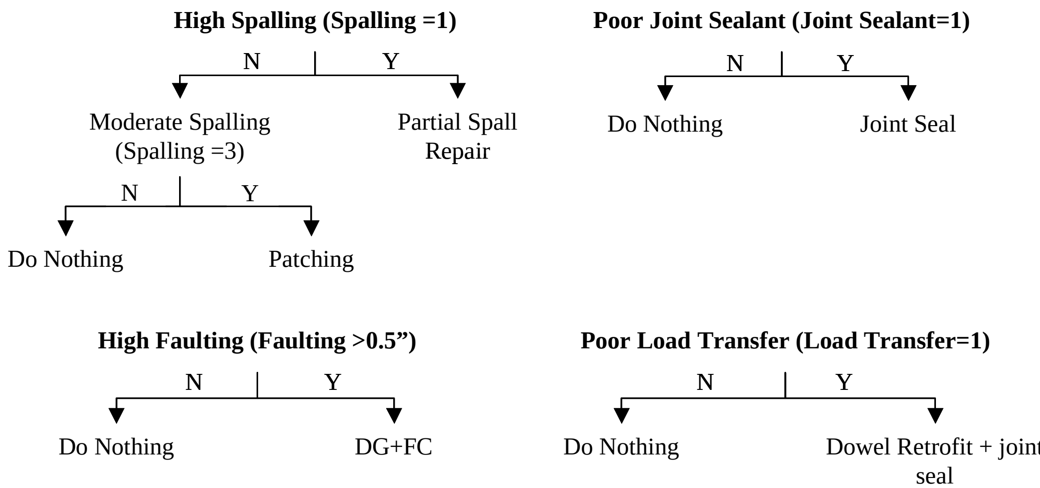

Figure 5.30: Corrective Maintenance DT for PCC Pavements

5.9.3 Maintenance and Rehabilitation Decision Trees

Table 5.17 summarizes the pavement performance limits used in the development of the DT for AC pavement sections, for both Interstate and Non-Interstate routes. These limits were developed using the historic performance data for ADOT highways available from the ADOT HPMA and through discussions with ADOT staff. In the table, Level I describes an acceptable condition, Level II a triggered condition, while Level III denotes failure. The limit between Level I and Level II defines the trigger level, while the limit between Level II and Level III defines failure level.

Table 5.17: Performance Levels For AC Pavements Decision Trees

Parameter	Interstate Routes			Non-Interstate Routes		
	Level I	Level II	Level III	Level I	Level II	Level III
Cracking	≤ 5%	> 5% and ≤ 20%	> 20%	≤ 8%	>8% and ≤ 25%	> 25%
Roughness	PSR ≥ 4.0	4.0 > PSR ≥ 3.2	PSR < 3.2	PSR ≥ 3.6	3.6 > PSR ≥ 2.8	PSR < 2.8
Rutting	≤ 0.5	> 0.5 and ≤ 1.0	> 1.0	≤ 0.5	>0.5 and ≤ 1.0	> 1.0
Flushing	≥ 3.5	< 3.5 and ≥ 2.5	< 2.5	≥ 3.5	< 3.5 and ≥ 2.5	< 2.5

Table 5.18 summarizes the pavement performance limits used in the development of the DT for PCC pavement sections, for both Interstate and Non-Interstate routes. As for AC pavement sections, these limits were also developed using the historic performance data for ADOT highways available from the AZ HPMA and through discussions with ADOT personnel. As can be noted, the limits for both the Interstate and Non-Interstate routes are similar due to the special nature of the rigid pavement sections, and the limited number of sections from that pavement type in the Non-Interstate of Arizona.

Table 5.18: Performance Levels For PCC Pavements Decision Trees.

Parameter	Interstate Routes			Non-Interstate Routes		
	Level I	**Level II**	**Level III**	**Level I**	**Level II**	**Level III**
Roughness	PSR ≥ 4.0	4.0 > PSR ≥ 3.1	PSR < 3.1	PSR ≥ 3.6	3.6 > PSR ≥ 3.1	PSR < 3.1
Corner Breaks (count)	≤ 10	> 10 and ≤ 20	> 20	≤ 10	> 10 and ≤ 20	> 20
Faulting (in)	≤ 0.2	> 0.2 and ≤ 0.5	> 0.5	≤ 0.2	> 0.2 and ≤ 0.5	> 0.5
Transverse Cracking	≤ 10	> 10 and ≤ 20	> 20	≤ 10	> 10 and ≤ 20	> 20

5.9.3.1 M&R Decision Trees for AC Pavements

The following assumptions were made during the development of the decision trees for AC pavements, based on historic records and discussion with ADOT staff:

- A section will be considered as "failed" if it reaches the failure level for any of the performance parameters considered in the analysis.
- Sections failing in cracking will require major rehabilitation activity (or reconstruction) to remove and replace the failed AC layers.
- Sections with high rutting and high cracking are considered to have possible base problems and will require reconstruction.
- Flushing issues are treated by removing and replacing the top AC layer.
- In cases involving cracking problems, it is usually recommended to use rubberized asphalt rather than regular asphalt during rehabilitation.
- Major performance conditions override less prominent surface problems. As an example, the level of flushing will not affect the rehabilitation decision for a pavement section that has already failed in cracking.

Figure 5.31 shows the M&R decision tree for AC pavement sections on Interstate routes. Table 5.19 describes each of the end nodes for the trees. Figure 5.32 shows two alternatives for the M&R decision tree for AC pavement sections on Non-Interstate routes, whereas Table 5.20 describes each of the end nodes.

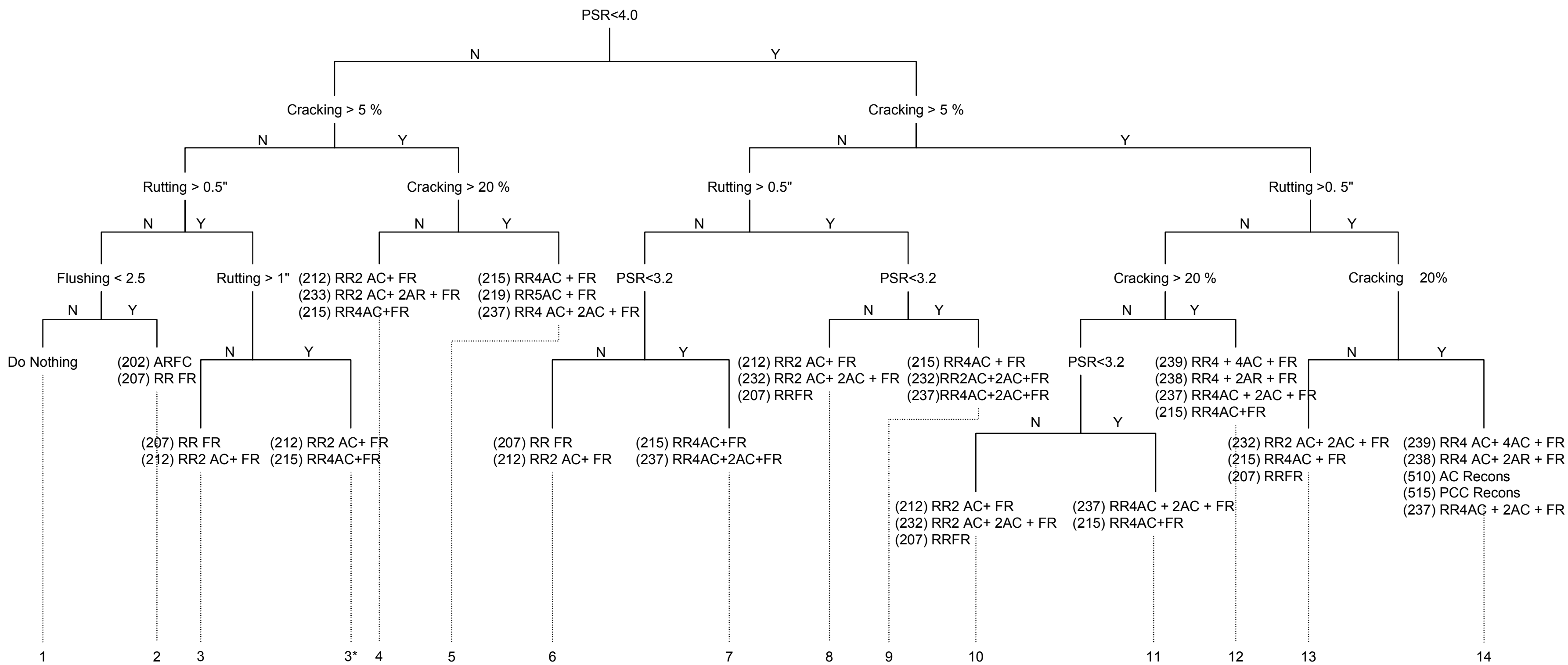

Figure 5.31: M&R Decision Tree for AC Pavements on Interstate Routes

Table 5.19: Description of Decision Tree End Nodes for Interstate AC Pavements

Node	Description	Possible Pavement Condition	Recommendation
1	Pavement in Good Condition	No Issues	Do Nothing / Preventive Maintenance
2	Flushing Failure No Cracking Problem	Flushing problem	Surface treatment Major Maintenance
3	Rutting Problem No Cracking Problem	AC problem	Rehabilitation - Remove and replace surface layer Regular AC may be used
4	Triggered in Cracking	AC issue	Surface treatment Major Maintenance
5	Failed in Cracking	AC failure	Major Rehabilitation
6	Triggered in IRI No Cracking Problem No Rutting Problem	Roughness Problem	Remove and replace AC non-rubberized AC may be used
7	Failed in IRI No Rutting No Cracking Problem	Roughness Failure	AC Rehabilitation
8	Rutting Problem Triggered in IRI No Cracking Problem	AC mix problem	Rehabilitation - Remove and replace surface layer
9	Failed in IRI Rutting Problem	AC failure	Major Rehabilitation
10	Triggered in Cracking and IRI	AC mix problem	Remove and replace top AC
11	Failure in IRI Triggered in Cracking	AC failure	Major Rehabilitation
12	Failed in Cracking	AC failure	Major Rehabilitation
13	Triggered in Cracking Triggered in IRI Rutting Problem	AC failure	Major Rehabilitation
14	Failure in Cracking and Rutting Triggered in IRI	AC failure Probable base Failure	Major Rehabilitation Reconstruction

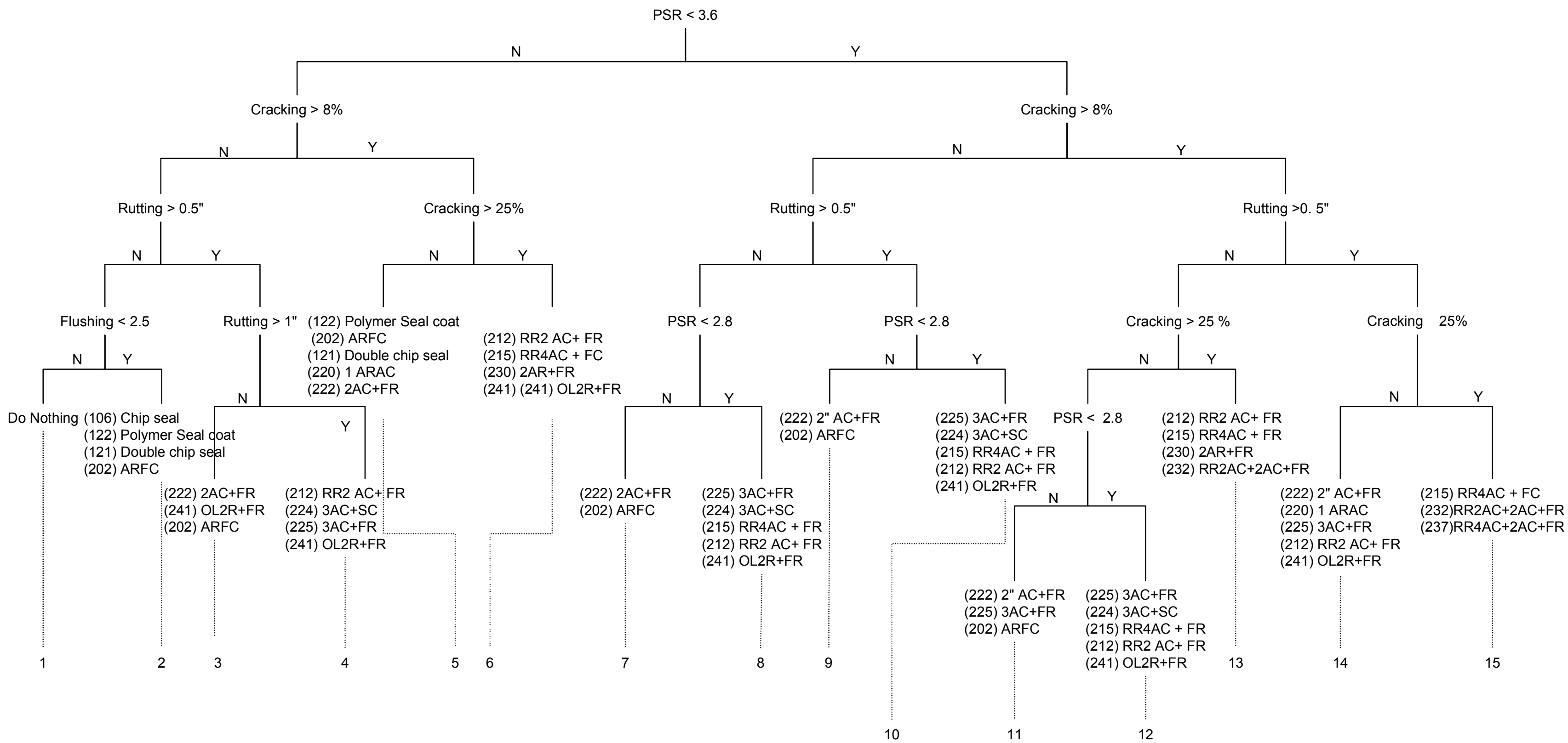

Figure 5.32: M&R Decision Tree for AC Pavements on Non-Interstate Routes

Table 5.20: Description of Decision Tree End Nodes for Non-Interstate AC Pavements

Node	Description	Possible Pavement Condition	Recommendation
1	Pavement in Good Condition	No Issues	Do Nothing / Preventive Maintenance
2	Flushing Failure No Cracking Problem	Flushing problem	Surface treatment Major Maintenance
3	Rutting Problem No Cracking Problem	AC mix problem	Surface treatment Major Maintenance
4	Rutting Failure No Cracking Problem	AC mix problem	Rehabilitation
5	Triggered in Cracking	AC issue	Surface treatment Major Maintenance
6	Failed in Cracking	AC failure	Major Rehabilitation
7	Triggered in IRI No Cracking Problem No Rutting Problem	Roughness Problem	Remove and replace AC Regular AC may be used
8	Failed in IRI No Rutting No Cracking Problem	Roughness Failure	AC Rehabilitation
9	Rutting Problem Triggered in IRI No Cracking Problem	AC mix problem	Rehabilitation - Remove and replace surface layer
10	Failed in IRI Rutting Problem	AC failure	Major Rehabilitation
11	Triggered in Cracking and IRI	AC mix problem	Remove and replace top AC
12	Failure in IRI Triggered in Cracking	AC failure	Major Rehabilitation
13	Failed in Cracking	AC failure	Major Rehabilitation
14	Triggered in Cracking Triggered in IRI Rutting Problem	AC failure	Major Rehabilitation
15	Failure in Cracking Rutting Problems Triggered in IRI	AC failure Probable base Failure	Major Rehabilitation Reconstruction

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5.9.3.2 M&R Decision Trees for PCC Pavements

The following assumptions were used during the development of the decision trees for PCC pavements, and were mainly based on discussions with ADOT staff and engineering judgment:

- A section will be considered as "failed" if the majority of slabs have cracked.
- Roughness and faulting would generally require grinding and a thin friction course.
- Higher number of cracks would require joint and slab repair and an AC overlay.

Figure 5.33 and Figure 5.34 show the M&R decision trees for PCC sections on Interstate and Non-Interstate routes, respectively. As can be noted from the figures, both trees are similar with the exception of the PSR trigger levels.

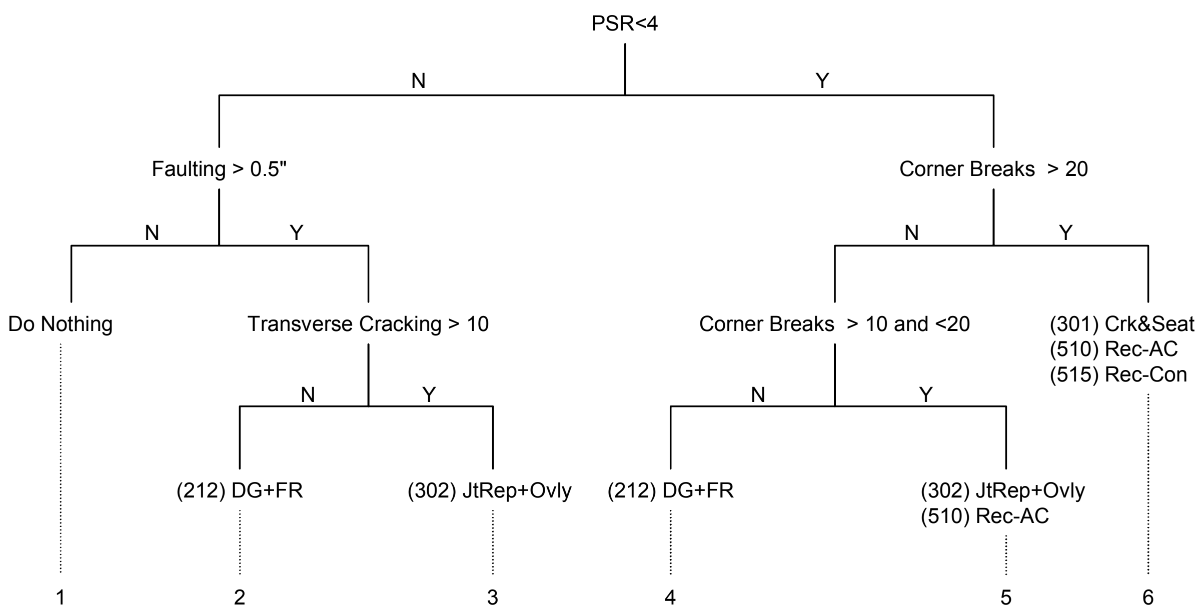


Figure 5.33: M&R Decision Tree for Interstate PCC Pavements

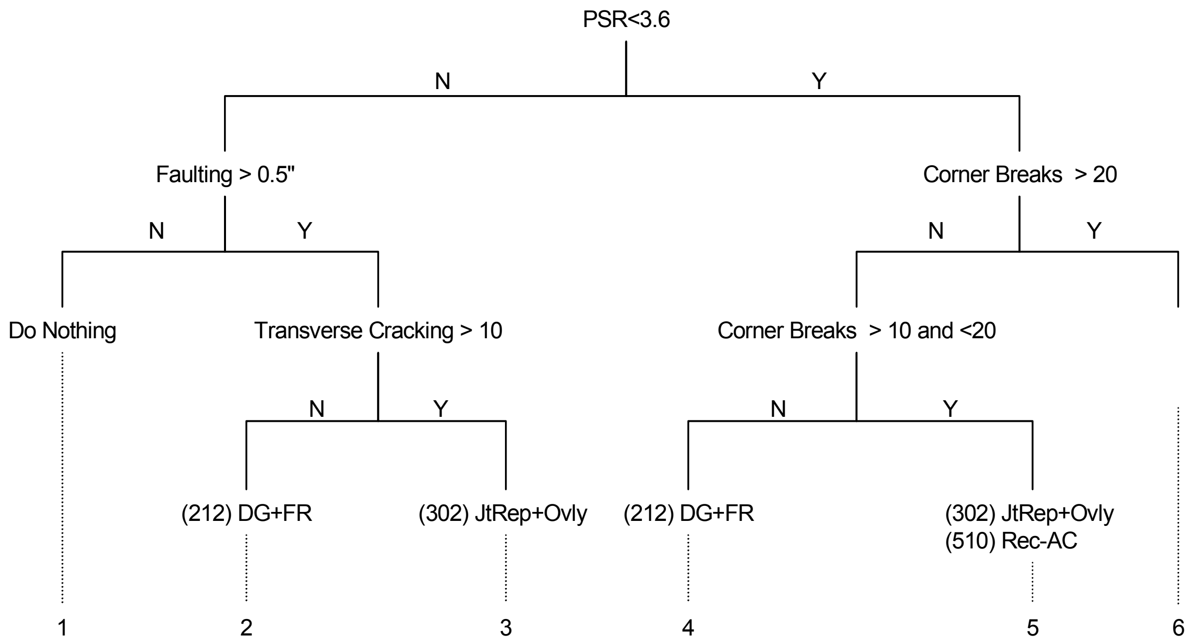


Figure 5.34: M&R Decision Tree for Non-Interstate PCC Pavements

Table 5.21 describes the end nodes and recommended treatments

Table 5.21: Description of Decision Tree End Nodes for PCC Pavements

Node	Description	Possible Pavement Condition	Recommendation
1	Low Roughness and Low Faulting	Pavement in Acceptable Condition	Do Nothing / Preventive Maintenance
2	Moderate Faulting with Low Cracking	Faulting problem	Grind and add a friction course
3	Moderate Faulting with High Cracking	Faulting problem	Repair joints and Slab AC Overlay
4	Triggered in Roughness Moderate Corner Breaks	Corner cracks	Grind and add a friction course
5	Triggered in Roughness High Corner Breaks	Pavement in Deteriorated Condition	Repair joints and Slab AC Overlay
6	Failed in Cracking	Pavement Failure	Reconstruction

6.0 STATE WIDE ANALYSIS

A statewide analysis to demonstrate these analysis modules is carried out using historic ADOT data. The analysis includes identifying ADOT's network budgetary needs and network performance using historic data and comparing these results to actual measured performance data. The results of the analysis show that the ADOT HPMA successfully modeled the historic trends of ADOT pavements and accurately represented ADOT's network conditions.

To demonstrate ADOT HPMA software performance and verify the analysis settings and models in the software, two sets of analyses were performed using the ADOT HPMA. The analyses were performed starting from the year 2000. Thus, the performance data from the following years were not considered in the analysis. The analysis results were subsequently evaluated against the actual data from the years 2000 through 2003.

The objective of the first analysis set was to predict the funding levels for the network required to achieve specific performance levels over the years 2000 through 2003. These performance levels are the actual measured performance of ADOT during this period. The analysis results are then compared to the actual funding levels provided by ADOT during the same analysis period.

The objective of the second analysis was to predict the network performance under a specific budget stream over the years 2000 through 2003. Again, this budget represents the actual budget spent over the analysis period, and the analysis results are compared to the actual network performance over the same period.

A section data view was first built for the entire ADOT highway network, using the year 2000 as a base year. M&R analysis was then performed to determine the feasible treatments for each section of the section data view. Optimization analysis was performed for each of the two analysis sets, subject to the required constraints and compared to the actual measured data, as described in the following subsections.

6.1 BUILDING A SECTION DATA VIEW

A section data view was built for the entire ADOT highway network, using Function 5-1 in ADOT HPMA. Figure 6.1 shows a screen capture of the section data view developed for the analysis. The analysis base year was set to the year 2000. Therefore, the section performance (Do-Nothing) was evaluated starting from the year 2000 and ignoring measured data in future years. Future performance, starting from the year 2000, of each section was predicted using site-specific models. However, in the absence of historic data or if the site-specific model did not result in reasonable prediction models, default models were used.

During the section data view building, all attributes for each section, including the performance, geometric attributes, etc., are evaluated to be used for M&R analysis and optimization. The total number of sections in this section data view was approximately 2000, ranging in length between 0.9 and 8.0 miles.

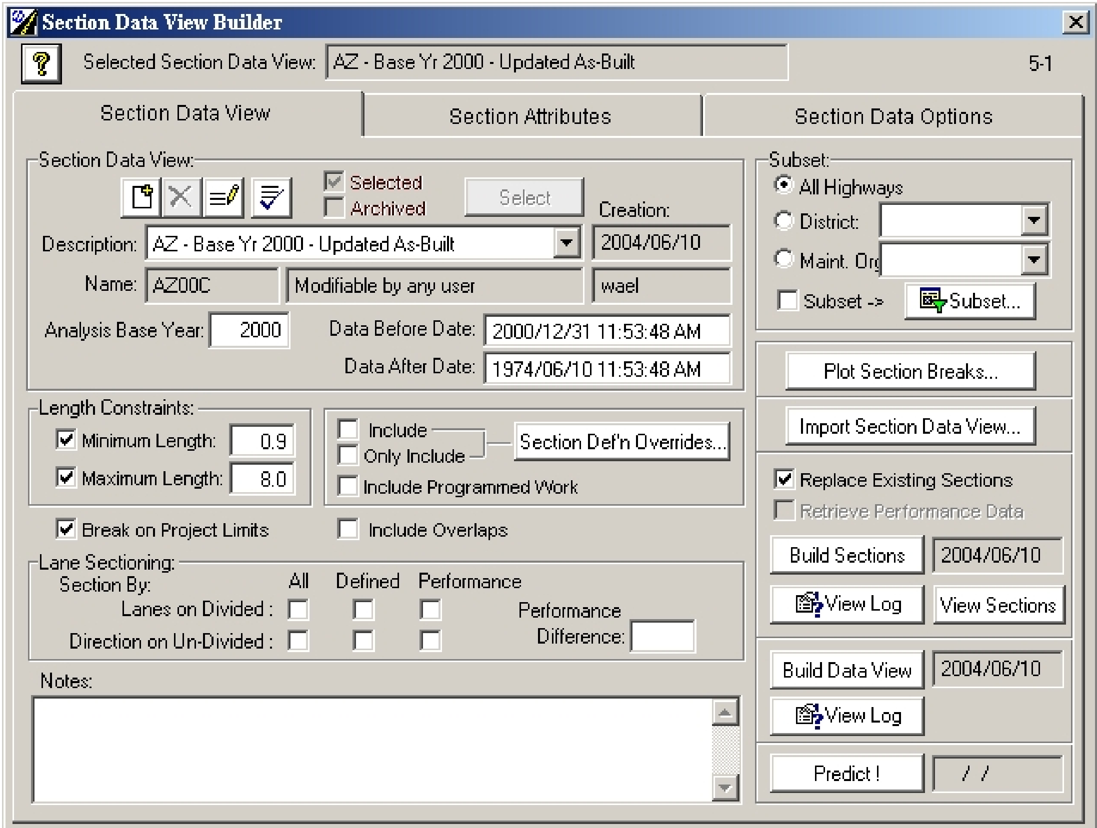


Figure 6.1: Building of a Section Data View

6.2 M&R ANALYSIS

M&R analysis was performed for all the sections in the section data view, using Function 6-2 in ADOT HPMA. The analysis period was set to 5 years (2000 through 2004). The objective of the M&R analysis is to identify all the feasible rehabilitation activities for each section in the section data view, using the M&R decision trees, described earlier in previous sections of this report. Also at this stage, the cost and the effectiveness of each of the feasible rehabilitation activities are calculated.

Figure 6.2 shows the analysis settings used for the M&R analysis. As can be noted, the Section Analysis was performed using an “Always Analyze” option and a “Single Implementation” option was selected for the Section Strategies.

The "Always Analyze" option causes the analysis to be carried for all the sections regardless of the need year, or when the section is actually triggered for rehabilitation. This option was used to capture minor rehabilitation activities, such as adding a friction course. However, the analysis will still be controlled through the decision trees, where sections in good conditions will not receive any rehabilitation.

A "Single Implementation" option was used since the analysis period is only 5 years, and it is not expected that any of the sections considered in the analysis will require any repeated implementation within this short analysis period.

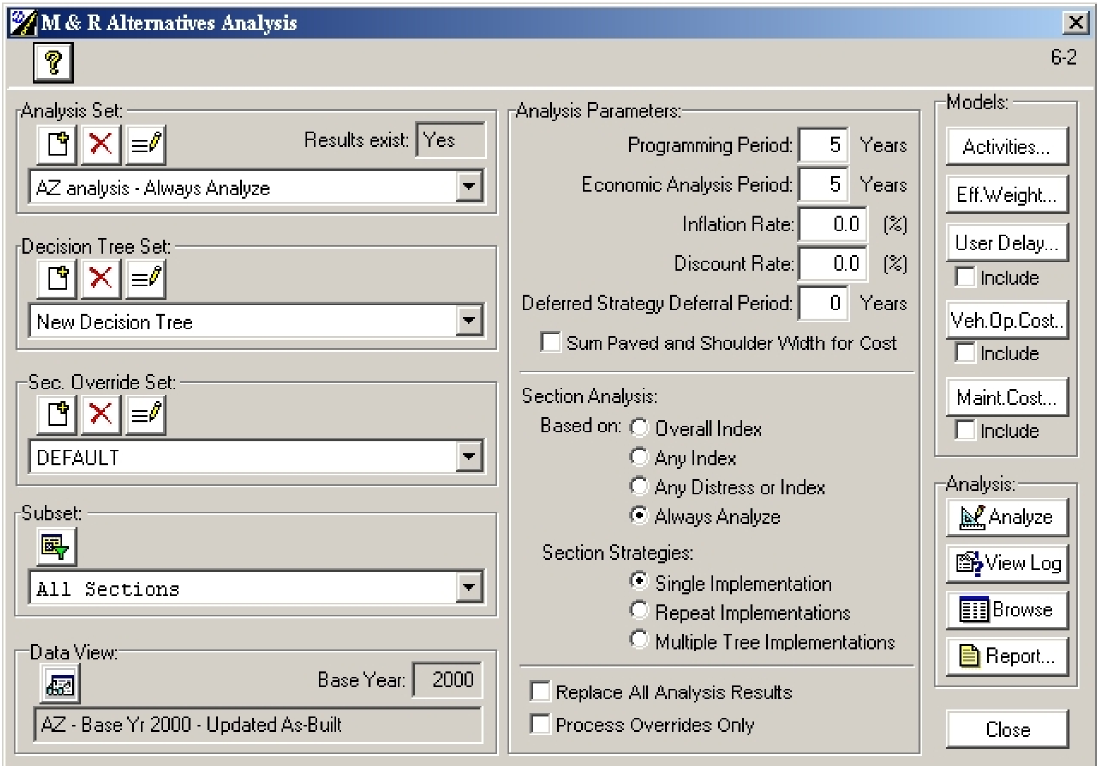


Figure 6.2: M&R Analysis Settings

6.3 OPTIMIZATION ANALYSIS

As mentioned earlier, two sets of analyses were performed using the same M&R analysis results, which are:

- Needs analysis to identify the network budgetary needs based on performance constraints
- Budget analysis to identify the network performance based on budget constraints

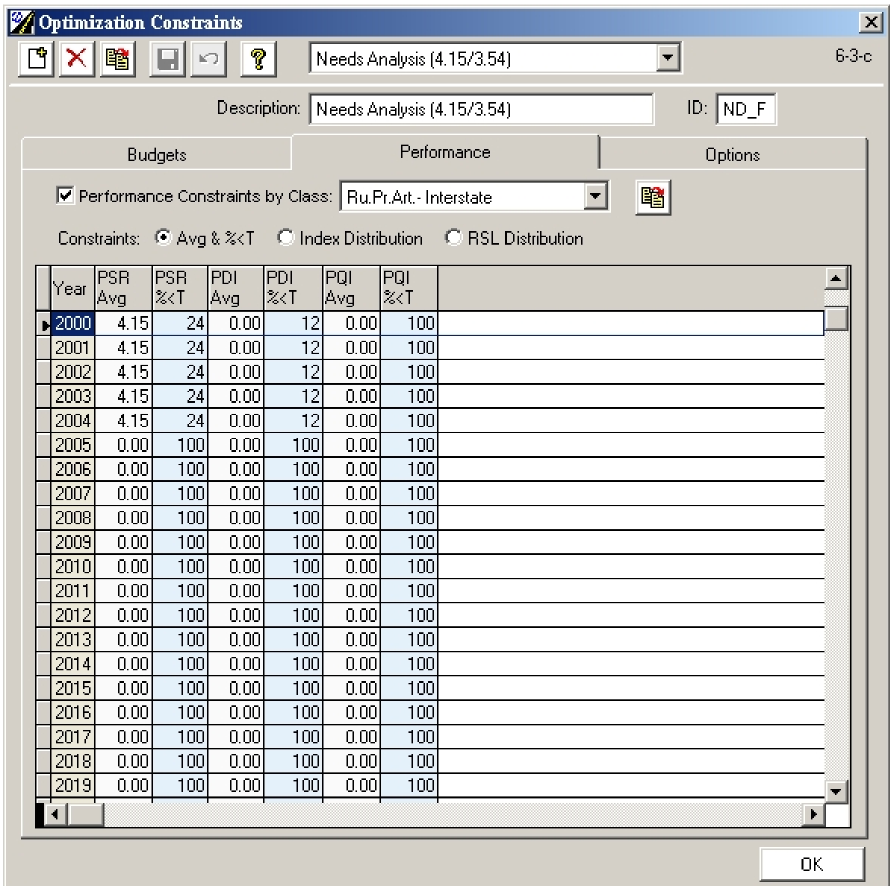
6.3.1 Needs Analysis Settings

The Needs Analysis was performed by specifying the network performance constraints in terms of roughness and distresses. The performance constraints used in the analysis are as shown in Table 6.1. As can be noted, the performance constraints are defined in terms of the network average and/or the percentage of the network lengths greater than a specific performance level. It should be noted that these performance constraints were set by ADOT, and on average represents the actual performance of ADOT highway network during the period between the years 2000 and 2003.

Table 6.1: Needs Analysis Perfromance Constraints

Constraint	Route Type	
	Interstate	Non-Interstate
% Network with PSR ≥ 3.5	76%	76%
Average PSR	4.15	3.54
% Network with Cracking ≤ 15%	88%	88%

The optimization analysis is performed using Function 6-3 in ADOT HPMA. The Needs analysis constraints are defined using the Function 6-3-c, where the budget is set to "-1" denoting an unlimited budget, while the performance constraints are set for each of the road types/functional class separately, as shown in Figure 6.3. As can be noted from the figure, the performance constraints in ADOT HPMA can be defined in terms of the network average and/or the percentage of the network length less the trigger level for any of the performance indices defined in the system.



Year	PSR Avg	PSR %<T	PDI Avg	PDI %<T	PQI Avg	PQI %<T
2000	4.15	24	0.00	12	0.00	100
2001	4.15	24	0.00	12	0.00	100
2002	4.15	24	0.00	12	0.00	100
2003	4.15	24	0.00	12	0.00	100
2004	4.15	24	0.00	12	0.00	100
2005	0.00	100	0.00	100	0.00	100
2006	0.00	100	0.00	100	0.00	100
2007	0.00	100	0.00	100	0.00	100
2008	0.00	100	0.00	100	0.00	100
2009	0.00	100	0.00	100	0.00	100
2010	0.00	100	0.00	100	0.00	100
2011	0.00	100	0.00	100	0.00	100
2012	0.00	100	0.00	100	0.00	100
2013	0.00	100	0.00	100	0.00	100
2014	0.00	100	0.00	100	0.00	100
2015	0.00	100	0.00	100	0.00	100
2016	0.00	100	0.00	100	0.00	100
2017	0.00	100	0.00	100	0.00	100
2018	0.00	100	0.00	100	0.00	100
2019	0.00	100	0.00	100	0.00	100

Figure 6.3: Needs Analysis Performance Constraints

6.3.2 Needs Analysis Results

The Needs analysis was performed to identify the funding levels required to maintain the network conditions at the desired levels. Figure 6.4 shows the budget required to achieve all these constraints for all the analysis years (2000 through 2004). These results are very close to the actual spending of ADOT during the fiscal years 2000 through 2003, which are shown later in Table 6.2.

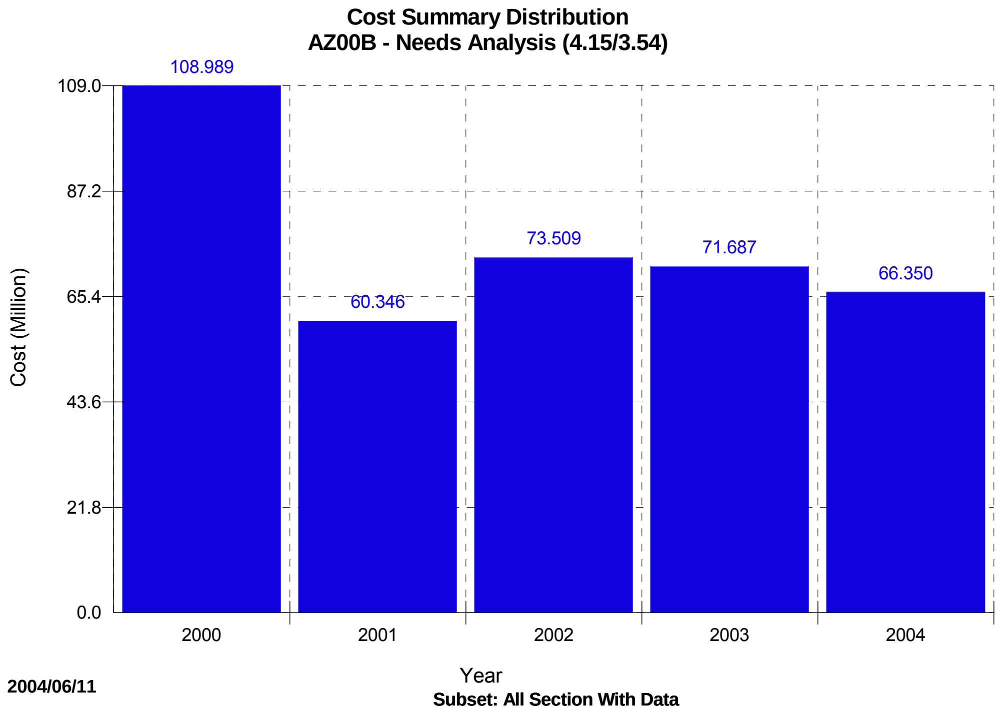


Figure 6.4: Budget Requirements based on Needs Analysis

Figure 6.5 shows the Interstate average PSR over the analysis period resulting from the Needs Analysis. Figure 6.6 shows the percentage PSR less than the performance trigger (PSR=3.5). Figure 6.7 shows the percentage with cracking more than 15%. As can be noted, the PSR network average constraint was exactly matched during the analysis, while the other constraints were exceeded. This is due to the fact that the software performs the analysis such that all the constraints are satisfied or exceeded.

Similarly, Figure 6.8 to Figure 6.10 show the Non-Interstate average PSR, percentage PSR less than the performance trigger (PSR=3.5), and percentage with cracking more than 15% over the analysis period resulting from the Needs Analysis, respectively. In this case, the percentage of the network less than the PSR trigger was the governing constraint, as it was exactly matched, while the other constraints were exceeded.

As can be noted from Figure 6.7 and Figure 6.10, which show the percentage of the Interstate and Non-Interstate sections with 15% or more cracking, respectively, the cracking levels are generally very low. This indicates that the cracking constraint was not controlling the analysis in either case. The main reason being that both the Interstate and Non-Interstate sections had very low cracking in the base year. Figure 6.11 and Figure 6.12 show the percentage of the Interstate and Non-Interstate sections with 15% or more cracks, respectively, based on Year 2000 measurements (0.2% for Interstate and 6.4% for Non-Interstate).

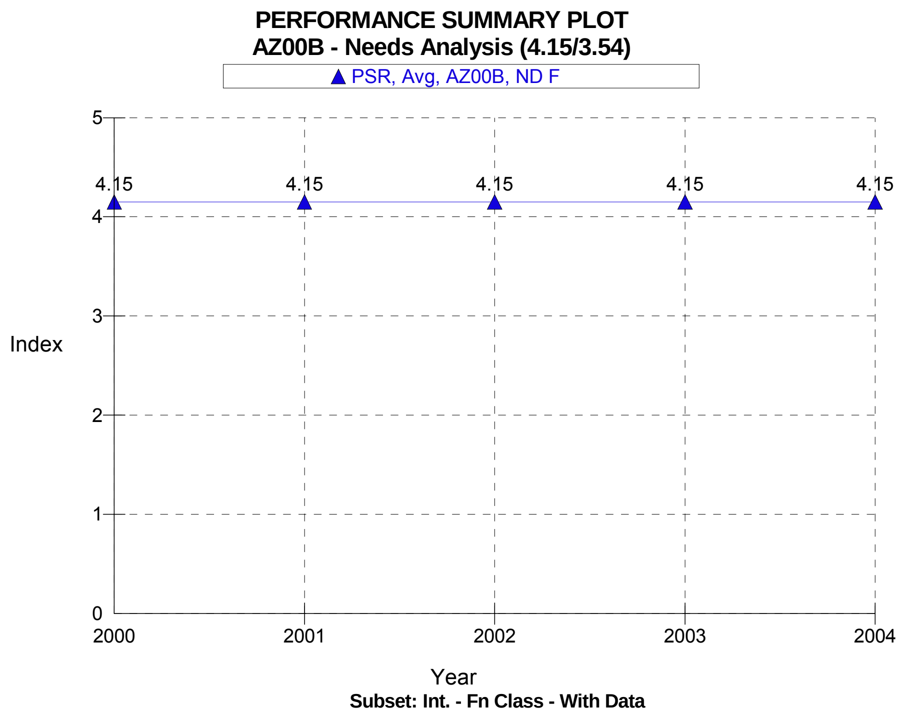


Figure 6.5: Interstate Average PSR based on Needs Analysis

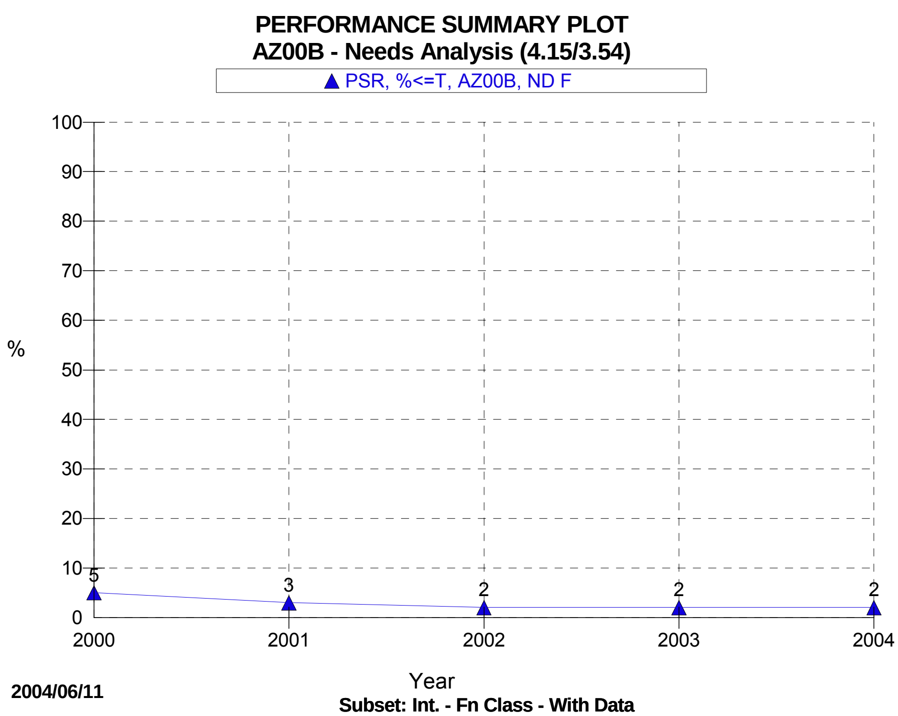


Figure 6.6: Percentage of Interstate Less than PSR based on Needs Analysis

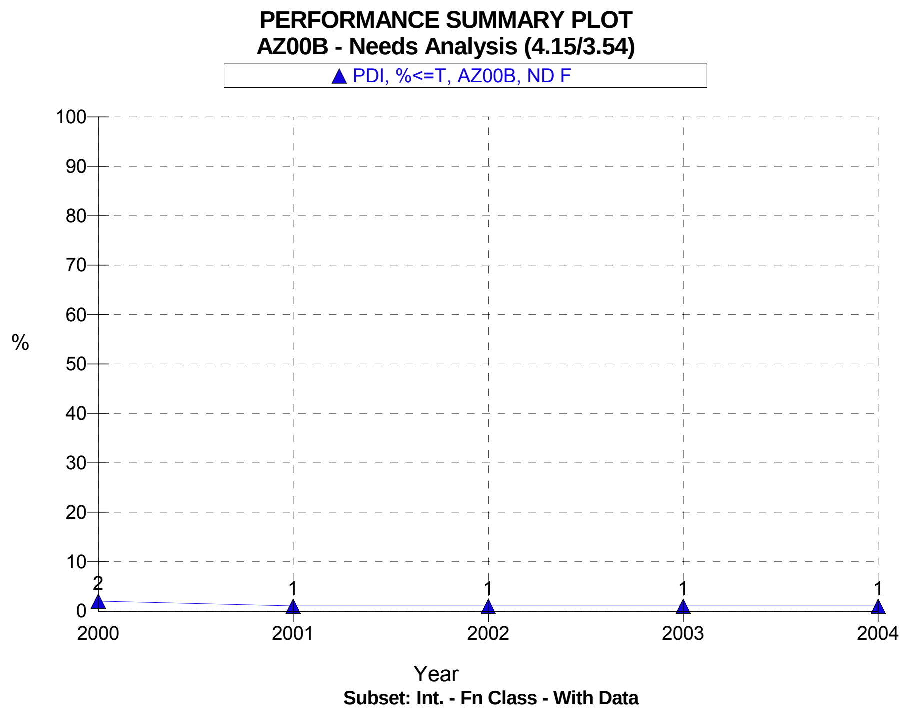


Figure 6.7: Percentage of Interstate with 15% or more Cracking based on Needs Analysis

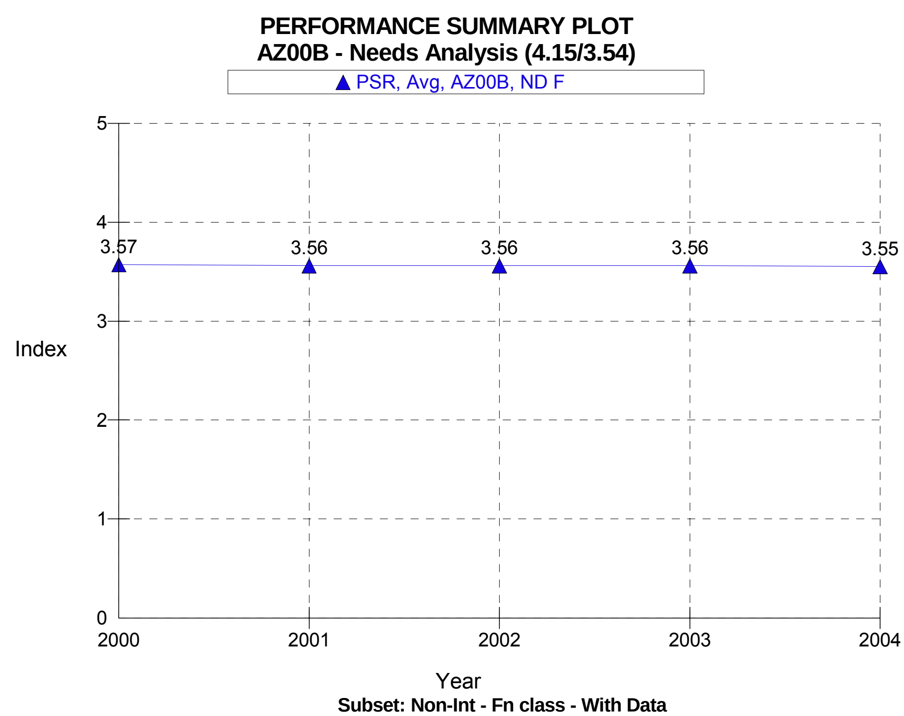


Figure 6.8: Non-Interstate Average PSR based on Needs Analysis

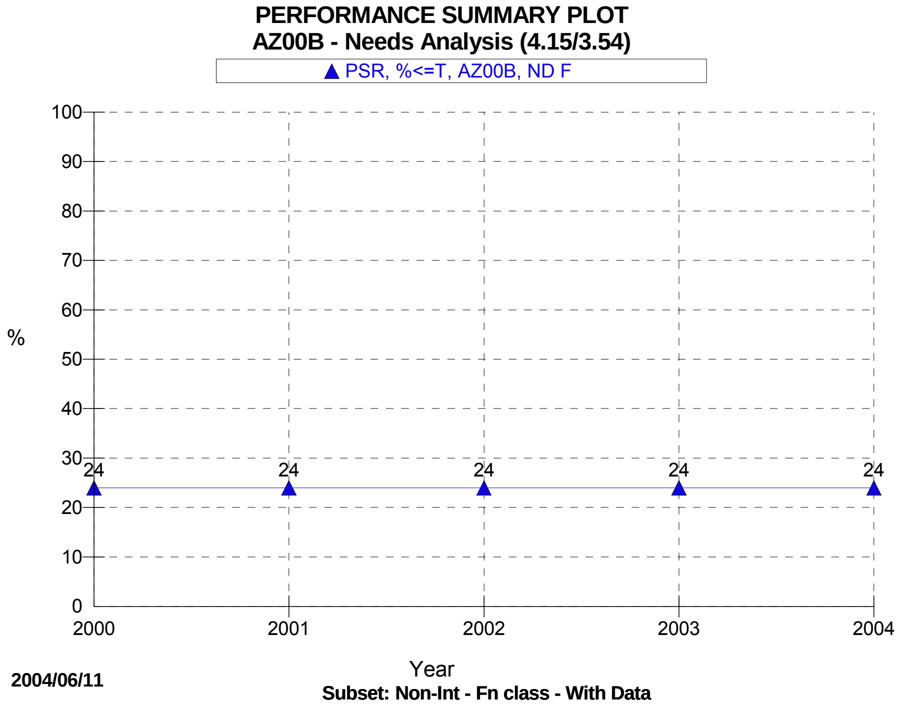


Figure 6.9: Percentage of Non-Interstate Less than PSR based on Needs Analysis

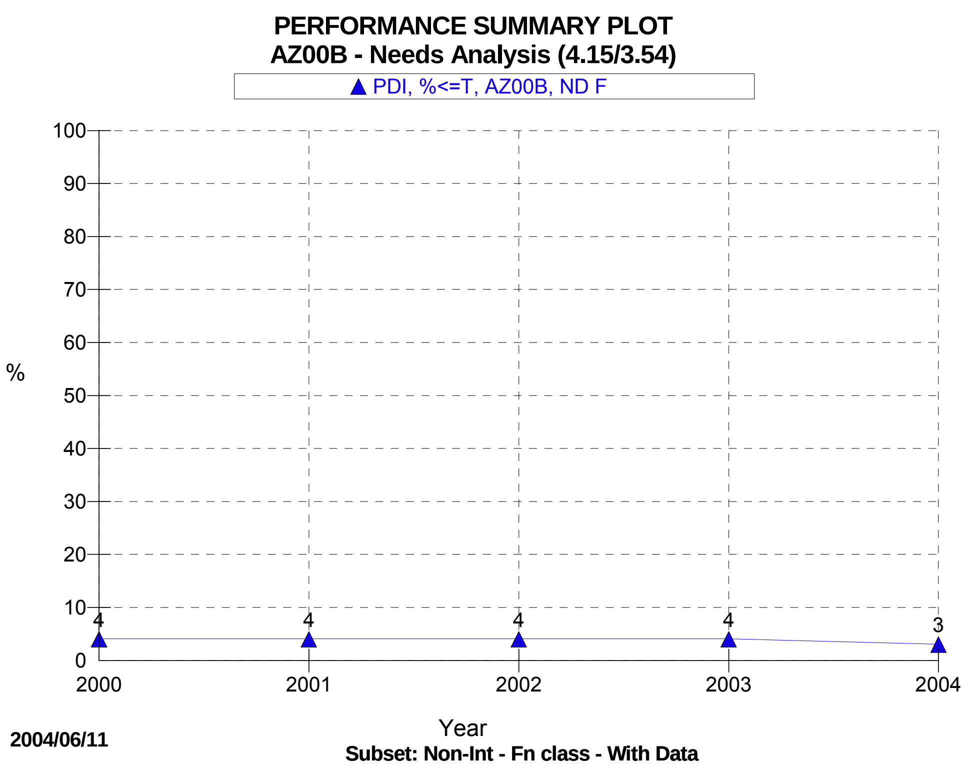


Figure 6.10: Percentage of Non-Interstate with 15% or more Cracking based on Needs Analysis

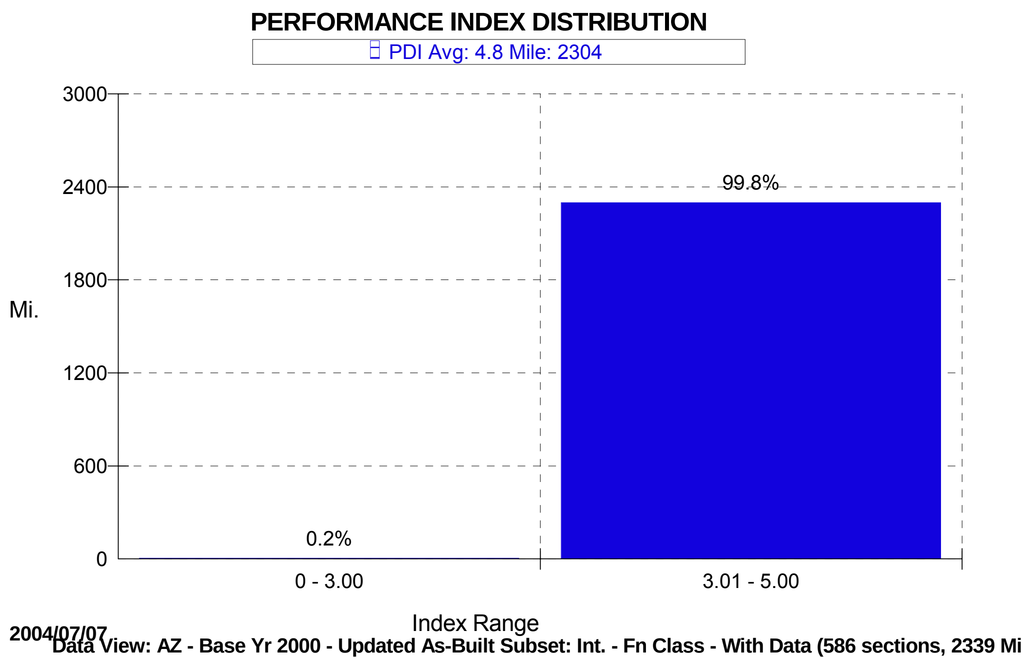


Figure 6.11: Measured Cracking for Interstate (Year 2000)

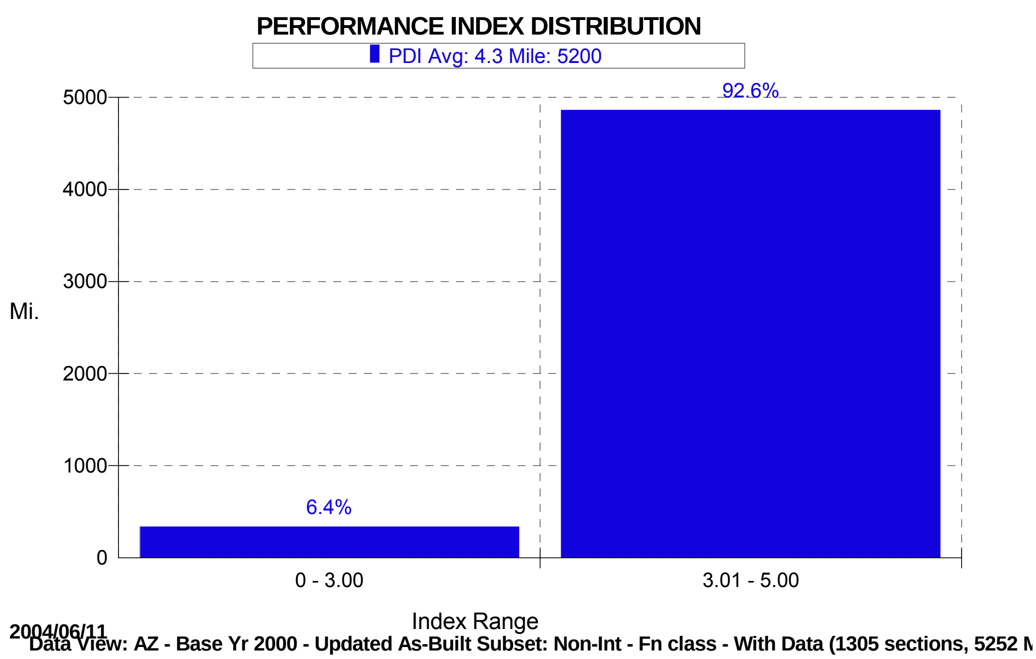


Figure 6.12: Measured Cracking for Non-Interstate (Year 2000)

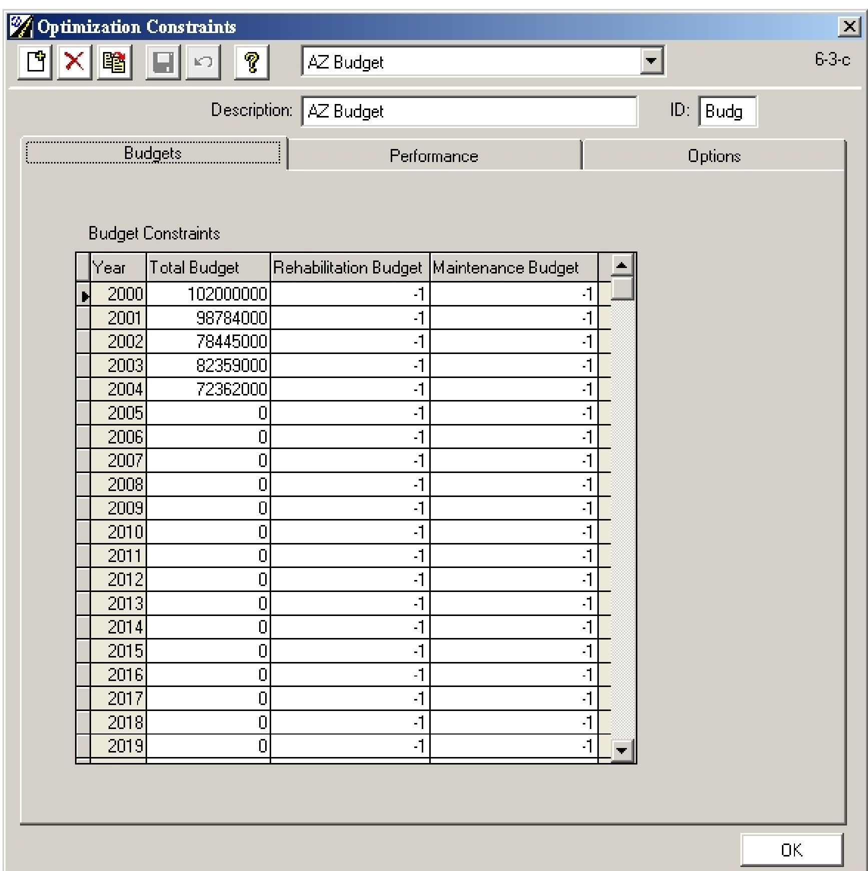
6.3.3 Budget Analysis Settings

The Budget analysis was performed using the yearly budget, shown in Table 6.2, as a budget constraint. The budget constraints used in the analysis were provided by ADOT and represent the actual budget used for the M&R projects during the analysis period.

Table 6.2: Budget Constraints for Optimization Anlaysis

Fiscal Year	Budget ($)
2000	102,000,000
2001	98,784,000
2002	78,445,000
2003	82,359,000
2004	72,362,000

Similar to the Needs analysis, the Budget constraints are defined using the Function 6-3-c, where the performance constraints were not defined, while the budget for each was defined as described in Table 6.2. Figure 6.13 shows the budget constraints as entered in ADOT HPMA for the budget analysis.



Year	Total Budget	Rehabilitation Budget	Maintenance Budget
2000	102000000	-1	-1
2001	98784000	-1	-1
2002	78445000	-1	-1
2003	82359000	-1	-1
2004	72362000	-1	-1
2005	0	-1	-1
2006	0	-1	-1
2007	0	-1	-1
2008	0	-1	-1
2009	0	-1	-1
2010	0	-1	-1
2011	0	-1	-1
2012	0	-1	-1
2013	0	-1	-1
2014	0	-1	-1
2015	0	-1	-1
2016	0	-1	-1
2017	0	-1	-1
2018	0	-1	-1
2019	0	-1	-1

Figure 6.13: Budget Constraints for Optimization Analysis

6.3.4 Budget Analysis Results

The analysis was performed using the budget constraints and the network performance results were extracted from the HPMA. In this section, the results of the analysis are shown for Interstate and Non-Interstate routes separately. However, it should be noted that the actual analysis was carried out for the entire network, where all the sections were "competing" for the available budget based on cost-effectiveness of the rehabilitation activities.

Figure 6.14 shows the average PSR for the Interstate sections over the analysis period, while Figure 6.15 shows the actual average PSR over the same period, as measured by ADOT and loaded to ADOT HPMA database. Table 6.3 shows the data from both graphs in a tabular format. As can be noted, the analysis results matched the actual measured data very closely.

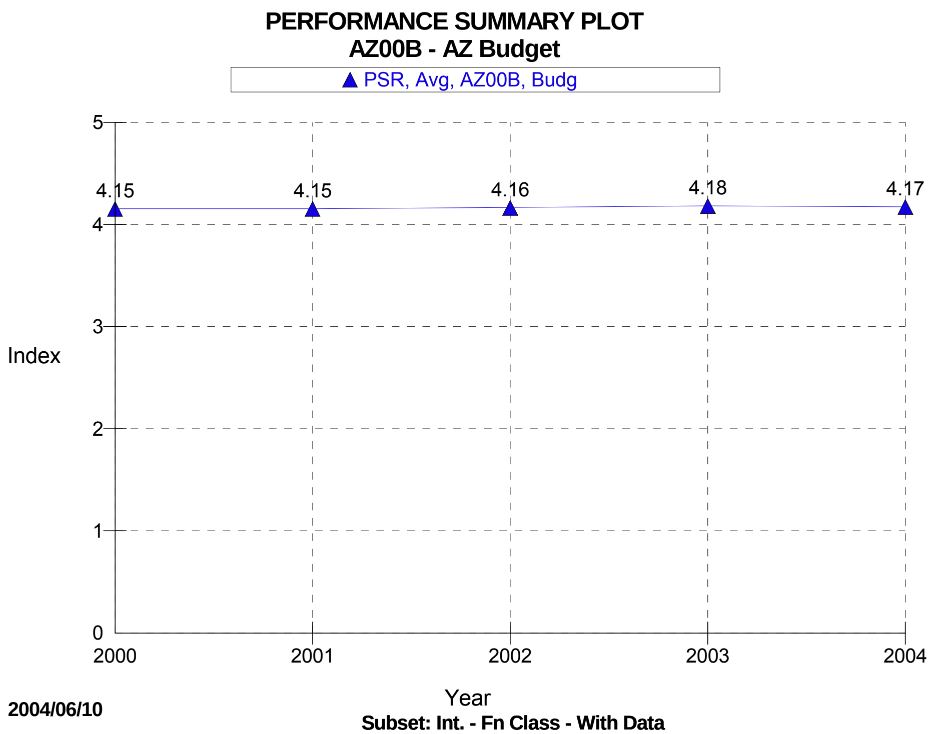


Figure 6.14: Summary of the Average Interstate PSR Based on Budget Analysis

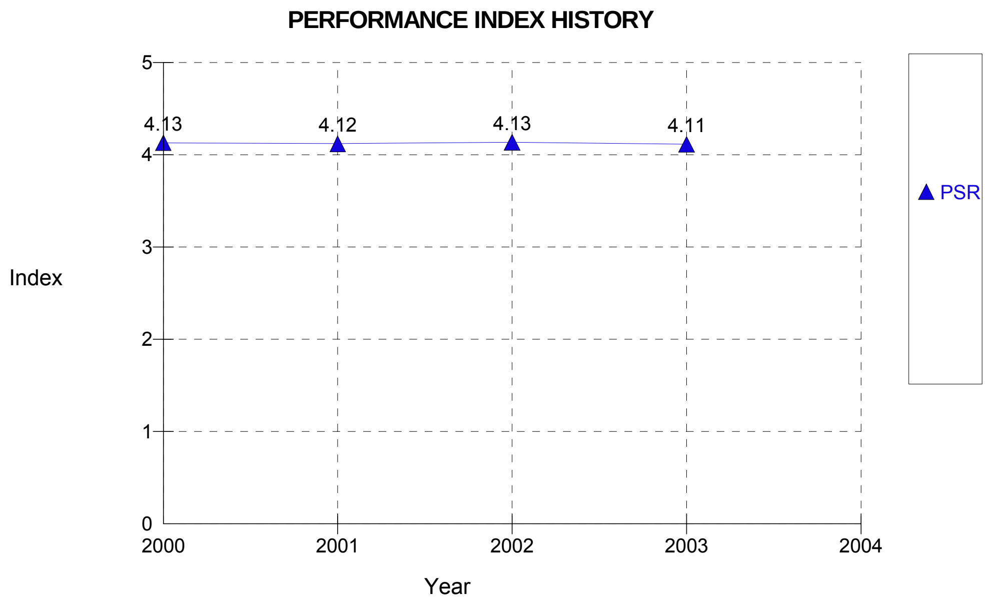


Figure 6.15: Summary of the Average Interstate PSR Based on Measured Data

Table 6.3: Comparison of PSR Average for Interstate Sections

Year	Actual Measured PSR	Predicted PSR
2000	4.13	4.15
2001	4.12	4.15
2002	4.13	4.16
2003	4.11	4.18

Figure 6.16 shows the percentage of the Interstate sections with a PSR less than 3.5 based on the budget analysis. These percentages are comparable to the actual measured data, which is shown in Figure 6.17. Table 6.4 shows a comparison between the predicted performance based on the budget analysis and the actual measured data for Interstate sections.

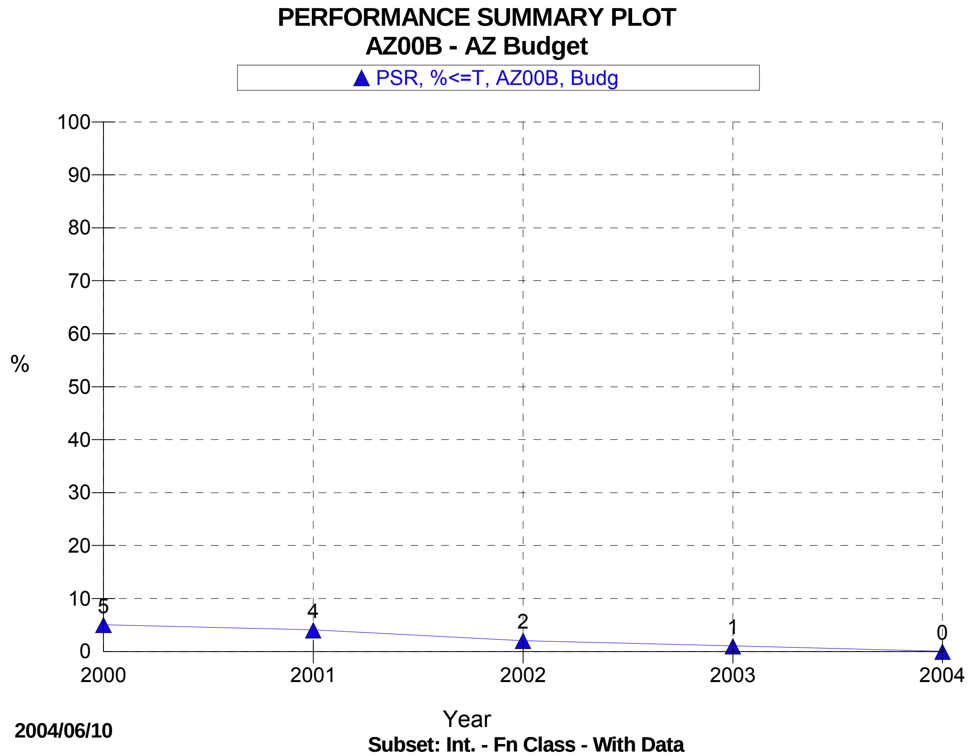


Figure 6.16: Percentage Interstate Sections with PSR < 3.5 Based on Budget Analysis

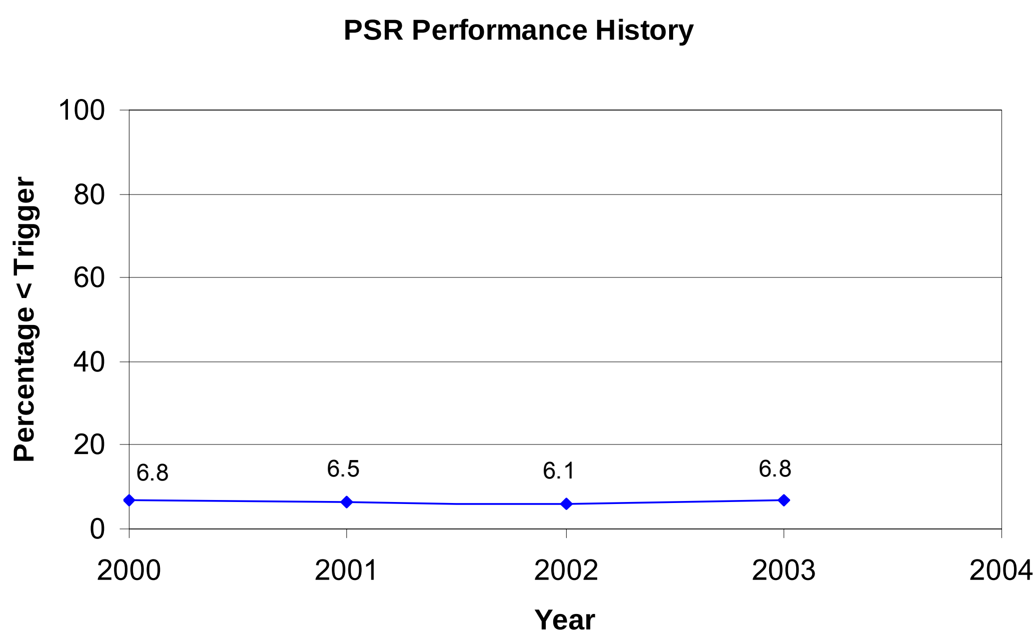


Figure 6.17: Percentage Interstate Sections with PSR < 3.5 Based on Measured Data

Table 6.4: Comparison of Sections with PSR < 3.5 for Interstate Sections

Year	Actual Percentage	Predicted Percentage
2000	6.8	5.0
2001	6.5	4.0
2002	6.1	2.0
2003	6.8	1.0

Similar to the results of the Interstate sections, Figure 6.18 shows the predicted PSR for the Non-Interstate sections based on the budget analysis, while Figure 6.19 shows the actual measured data. Again, Table 6.5 shows a comparison between the predicted performance based on the budget analysis and the actual measured data for Non-Interstate sections. As can be noted from the results, the difference between the predicted average PSR based on the analysis and the actual measured performance is not significant.

Figure 6.20 shows the percentage of the Non-Interstate sections with a PSR less than 3.2 based on the budget analysis. These percentages are comparable to the actual measured data, which is shown in Figure 6.21, especially at the later years of the analysis. Table 6.6 summarizes the predicted performance and the actual measured data for Non-Interstate sections.

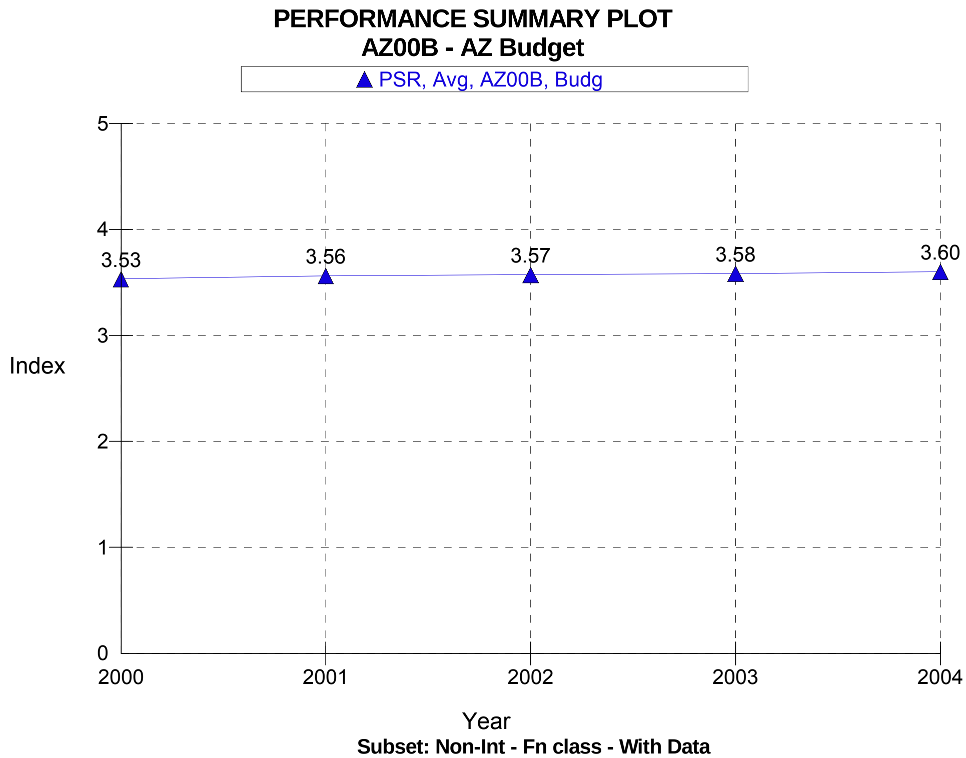


Figure 6.18: Summary of the Average Non-Interstate PSR Based on Budget Analysis

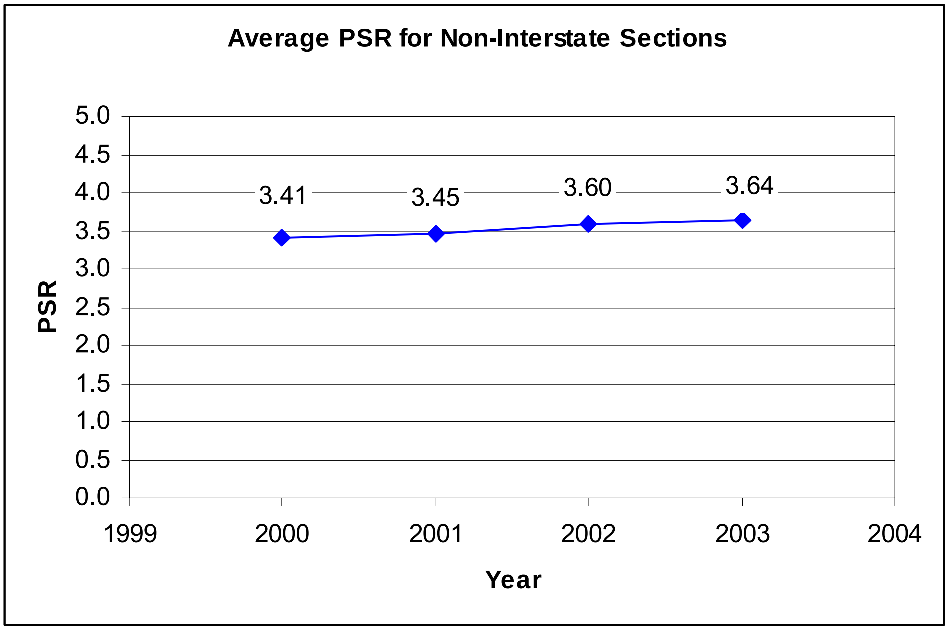


Figure 6.19: Summary of the Average Non-Interstate PSR Based on Measured Data

Table 6.5: Comparison of PSR Average for Non-Interstate Sections

Year	Actual Measured PSR	Predicted PSR
2000	3.41	3.53
2001	3.45	3.56
2002	3.60	3.57
2003	3.64	3.58

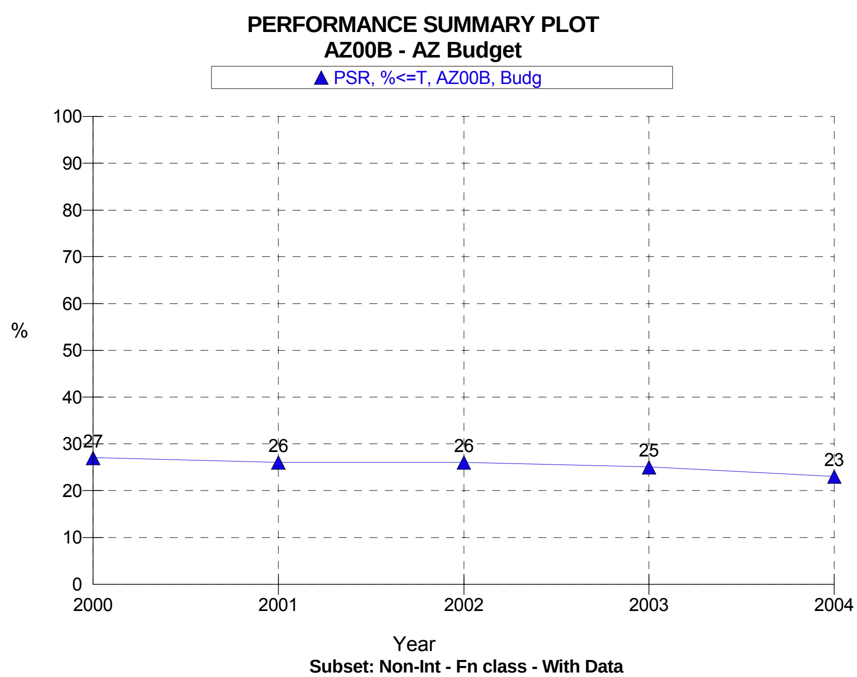


Figure 6.20: Percentage Non-Interstate Sections with PSR<3.2 Based on Budget Analysis

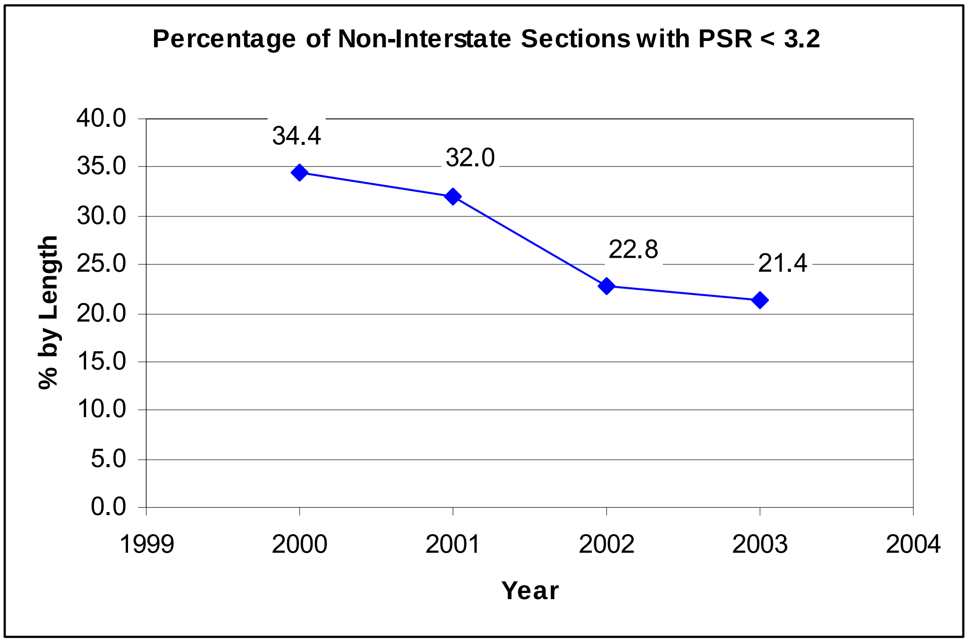


Figure 6.21: Percentage Non-Interstate Sections with PSR<3.2 Based on Measured Data

Table 6.6: Comparison of Sections with PSR < 3.2 for Non-Interstate Sections

Year	Actual Measured PSR	Predicted PSR
2000	34.4	27.0
2001	32.0	26.0
2002	22.8	26.0
2003	21.4	25.0

7.0 IMPLEMENTATION OF ADOT HPMA

The HPMA was installed at ADOT on the department's computer network using the SQL Server Database Management System to house the database. The application software (HPMA.EXE) is installed on each workstation PC accessing the database stored on the database server, as well as some setup and parameter files stored on a file server. This configuration is illustrated below.

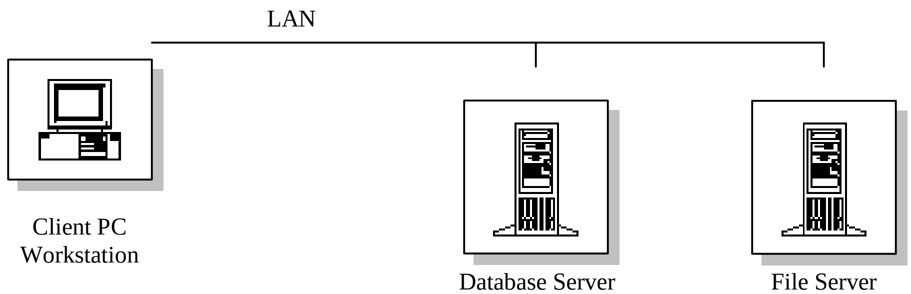


Figure 7.1: Client/Server Implementation at ADOT Using SQL Server Database Server

The HPMA database server utilizes a single SQL Server user for connection from the client workstations. Access to the SQL Server connection is controlled by the HPMA application. The HPMA application uses Open Database Connectivity (ODBC) to communicate with the database server. All client workstations must use the same ODBC connection name. The directory structure set up on the file server is as shown in Table 7.1.

Table 7.1: HPMA Directory Structure

Directory	Purpose
\HPMA_AZ	Base Directory
\adhocrpt	User-defined (ad-hoc) report forms
\data	HPMA parameter files (prm_*, etc.)
\help	HTML help files
\output	HPMA generated output files
\section \xxx \yyy	Subdirectories below Section are created by HPMA for each user-defined section data view
\temp	Temporary files
\sdv	Sdp_dict_*.*, prm_sdvb_*.* files
\transfer	*.cab files created using the export/import function

An additional folder (directory) was created on the file server to provide a central location for the storage of current versions of the HPMA executable (HPMA.EXE) and other components. It is referred to as the System Repository. The HPMA application checks the version stored in this location to determine if a newer version exists. The new version is then automatically copied to the workstation to replace the older version. This simplifies the updating of client machines when a new version of the .EXE file is provided.

The files to be included in the repository are:

- HPMA.EXE
- HPMA_SET.EXE
- HPMAUPDT.EXE
- EXEUPDT.EXE
- PMS_SETU.DBF (can be included as a source for copying to new workstations)

Each PC workstation is set up using the following steps (see the HPMA Installation Manual for more detail):

1. Run the PMSSetup8.exe to install the system components. This registers components and runtime libraries in the Windows registry. It also places two files in the designated application folder.
2. Set up the ODBC data source for the SQL Server database.
3. Copy the HPMA.EXE, HPMA_SET.EXE and PMS_SETU.DBF to the application folder.
4. Run HPMA_SET.EXE to make sure the paths and ODBC source are set correctly. (If the PMS_SETU.DBF is already set up correctly, this step is not necessary).