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Pavement Performance Data Extraction from the Caltrans PMS

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Partnered Pavement Research Program (PPRC) Contract Strategic Plan Element 3.2.5:
Documentation of Pavement Performance Data for Pavement Preservation Strategies and Evaluation of Cost-Effectiveness of Such Strategies

PREPARED FOR:

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Abstract: The Caltrans Pavement Management System (PMS) is a database of pavement condition survey data collected since 1978. Recording pavement condition using dynamic segmentation makes it difficult to monitor pavement performance for a fixed section of roadway because the boundaries of distress typically change with each successive field condition survey. The questions to be answered by this study are:

1. Can a method be developed to extract Caltrans PMS historical pavement condition data (based on dynamic segmentation) to show pavement performance trends?
2. Can the method show clear and useful trends in pavement performance for various types of pavements and condition?

This document presents the development of a method based on a weighting algorithm that apportions pavement condition data from dynamic segments to pavement sections (studied in other UCPRC research projects) that have fixed project limits. The capabilities and obstacles for the weighting algorithm method are presented.

Results from applying the method for various pavement types (rigid, flexible, and composite) and condition (distress and roughness) showed some success. All rigid pavement sections showed clear and useful trends for cracking but no discernible trends in faulting and spalling. Trends for cracking (initiation and progression) on flexible pavements were clear for over half the sections studied. Segment boundaries were much more dynamic on flexible pavements. Similar to rigid pavement sections, nearly all composite pavements produced clear and useful trends for cracking. Roughness measurements based on IRI showed differences between lanes and trends of decreasing roughness at a majority of sites, with some values below 50 inches per mile.

Keywords:
PMS, distress, pavement performance

Proposals for implementation:
Recommendations are made for further extraction of some distresses from the historical PMS database for use in calibrating mechanistic-empirical design models and pavement preservation treatment performance.

Related documents:

- Technical Memorandum (UCPRC-TM-2007-05): Performance of Pavement Preservation Treatments (1988 to 2003);
- Draft Research Report (UCPRC-RR-2002-04): Data Mining of the Caltrans Pavement Management System (PMS) Database
- Work Plan for: Performance Review of Pavement Preservation Treatments" (October 9, 2006). Prepared by the University of California Pavement Research Center, Berkeley and Davis, for the California Department of Transportation Division of Research and Innovation Office of Roadway Research and Division of Maintenance Office of Pavement Preservation

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PROJECT OBJECTIVES

The first and main objective of this study is to develop a methodology that enables historical pavement condition data to be extracted from the Caltrans Pavement Management System (PMS) to shows trends. The method must overcome or partly mitigate the confounding effects of dynamic segmentation of the pavement network.

The second objective of the study is to apply the method and to extract performance data to detect reasonable trends in pavement performance for various types of pavements and condition.

CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**Convert From**	**Multiply By**	**Convert To**	**Symbol**
LENGTH				
in	Inches	25.4	millimeters	mm
ft	Feet	0.305	meters	m
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m2
VOLUME				
ft^3	cubic feet	0.028	cubic meters	m^3
MASS				
lb	Pounds	0.454	kilograms	kg
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	C
FORCE and PRESSURE or STRESS				
lbf	Poundforce	4.45	newtons	N
lbf/in^2	poundforce/square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**Convert From**	**Multiply By**	**Convert To**	**Symbol**
LENGTH				
mm	Millimeters	0.039	inches	in
m	Meters	3.28	feet	ft
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
VOLUME				
m^3	cubic meters	35.314	cubic feet	ft^3
MASS				
kg	Kilograms	2.202	pounds	lb
TEMPERATURE (exact degrees)				
C	Celsius	1.8C+32	Fahrenheit	F
FORCE and PRESSURE or STRESS				
N	Newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce/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. (Revised March 2003)

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1. INTRODUCTION

1.1. Background

The Division of Maintenance of the California Department of Transportation (Caltrans) has an identified need to compare performance estimates for asphalt pavement preservation treatments with asphalt pavements that have had no pavement preservation treatment. This is a first step necessary to compare life-cycle costs of various pavement preservation treatments with each other as well as with "control" cases that have received no pavement preservation treatment after rehabilitation.

The University of California Pavement Research Center (UCPRC) had been working on Partnered Pavement Research Center Strategic Plan Element 3.2.5 (herein PPRC SPE 3.2.5), titled "Documentation of Pavement Performance Data for Pavement Preservation Strategies and Evaluation of Cost-Effectiveness of Such Strategies," Since October 2005. The goal of this SPE is to use performance prediction to recommend best pavement preservation practices. The original objectives of SPE 3.2.5 were:

1. To track pavement preservation projects through performance databases.
2. To estimate pavement performance for various strategies and application times relative to condition of the existing pavement.
3. To analyze life-cycle costs and recommend optimum timing and strategy selection.

In July 2006 the Division of Maintenance provided an additional $50,000 to the Division of Research and Innovation to enable the UCPRC to increase the scope of this research and overcome problems in completing the original objectives. The revised objectives of the project are as follows:

1. Identify pavement preservation treatments in the Pavement Condition Survey (PCS) data in the Caltrans Pavement Management System (PMS) databases.
2. Retrieve and review PCS data and other data from whatever sources are available so as to develop performance estimates.
3. Develop histories for condition survey performance
4. Perform statistical analysis to identify performance probabilities.
5. Analyze timing of pavement preservation treatments and effects on relative performance.
6. Calculate life-cycle costs.
7. Report the results of the investigation.

The revised objectives are stated in the "Work Plan for Performance Review of Pavement Preservation Treatments" (1). Each objective, its associated deliverables, and notes regarding their completion are presented in Table 1.1.

The objectives were intended to extract the best possible information from existing Caltrans databases and analyze it, to help improve practices for preserving pavements. The process included documenting past practice for pavement maintenance, as well as comparison with a "pavement preservation" approach to pavement maintenance. Pavement preservation seeks to optimize the use of maintenance resources through careful selection and timing of maintenance treatments, assisted by performance estimation and life-cycle cost analysis.

With the additional funding, data were collected for a larger number of pavement preservation treatments in the PCS database as well. The objectives were completed by the UCPRC working with the Division of Maintenance Office of Pavement Preservation (OPP), with assistance from the Office of Roadway Rehabilitation and the Office of Roadway Maintenance.

As of October 2006, it had been identified that the primary difficulty with completing the project lay in extracting performance data from the Caltrans PCS database due to dynamic segmentation, finding information regarding underlying pavement structures, and locating histories of rehabilitation and maintenance necessary to explain the condition survey data.

The purpose of this technical memorandum is to document the solution developed to overcome the problem of dynamic segmentation, and to document the ability of that solution to extract reasonable distress and ride-quality time histories from historical Caltrans Pavement Condition Survey (PCS) data. This technical memorandum completes the third objective in Table 1.1.

Table 1.1: Project Objectives, Deliverables, and Notes

Objective	Deliverables	Tech Memo Chapter	Notes
Identify Pavement Preservation (PP) treatments.	List of pavement preservation treatment sections constructed from 1993 to 2002; summary of gaps in the available data.	Not part of this memorandum	11 PP strategies, mostly dense-graded asphalt concrete overlays (ACOL-DG).
Retrieve and review Pavement Condition Survey (PCS) data and other data.	Database of pavement performance data (condition survey) extracted from PCS and containing traffic and climate data.	Ch. 2	Database created containing data for performance, climate, and truck traffic.
Develop condition survey performance histories.	Summary memorandum of pavement performance histories for sections in database.	Ch. 3, 4, 5	Flexible pavement performance: 78 sections; Rigid pavement performance: 46 sections ; Composite pavement performance : 53 sections ; IRI performance all sections listed above
Perform statistical analysis to identify performance probabilities.	Summary memorandum of statistical analysis of pavement performance for sections in database.	Not part of this memorandum	718 project sections were adequate after visual inspection. Visual inspection showed performance history did not meet criteria on 1,800 sections. Probability of failure for the pooled dataset complete for ACOL-DG based on Alligator A+B cracking. Developing refined probabilities based on traffic/climate factors.
Calculate life-cycle costs.	Summary memorandum of calculated life-cycle costs for pavement preservation treatments and control sections included in statistical analysis of performance.	Not part of this memorandum	Complete.
Analyze timing and relative performance.	Summary memorandum of historical maintenance patterns and estimated optimum timing of pavement preservation treatments based on life-cycle cost analysis.	Not part of this memorandum	Complete.
Report	Report summarizing all the work completed.		Draft version complete.

1.2. History and Related Studies

The California Department of Transportation (Caltrans) adopted a Pavement Management System (PMS) (2, 3) in 1979. At that time the PMS was developed to support a "worst first" approach to pavement maintenance. The 1978 Caltrans report by Bartell and Kampe (4) states the purposes in developing the Caltrans PMS:

- To monitor deteriorating pavement,
- To disseminate repair strategy information,
- To substantiate cost-effective rehabilitation strategies, and
- To use it as a basis for managing existing pavements in the State highway system

Caltrans first implemented its PMS when the concept of pavement management was relatively new, at a time when computers were not as powerful as they are today. Over the subsequent 25 years, there have been large improvements in computers as well as important changes in the theory and practice of pavement management, both in the way pavements are maintained in the State of California and within Caltrans itself. These changes have led to the slow evolution of the Caltrans PMS database. In particular, the database management software has been changed three times, with concurrent changes in the database structure. Changes have also been made in the structure and usage of various fields in the database and in the way that the PCS data are collected. These changes have been made primarily to improve the capability of the PMS to meet certain state pavement network management objectives, but the changes have sometimes made performance modeling more difficult because of lack of compatibility of the data fields across the changes.

The PMS structure and operations have achieved the following objectives:

- Identify distresses and ride quality in each year to determine whether pavement has reached "trigger" conditions for major maintenance and rehabilitation (M&R) work.
- Provide an annual network-level summary of distress and ride quality status, which can be reported to Caltrans upper management and the California Transportation Commission.
- Identify distresses needing attention by Maintenance Superintendents.

In achieving these objectives, the PMS has been able to provide comparisons of total lane-miles of distressed pavement and total lane-miles with various categories of ride quality summarized for the entire network from year to year. However, distresses and ride quality have not been tracked or compared from year to year for specific lane-miles within the network. Time histories of pavement distress and ride

quality tracked for individual segments of pavement are necessary, to gain an understanding of how different types of pavement deteriorate under various traffic, climate, and subgrade conditions, as well as to understand how the effects of rehabilitation, maintenance, and, more recently, pavement preservation affect pavement performance.

Since at least the 1990s, Caltrans has increasingly attempted to use PMS data to better understand pavement performance. While the objectives listed above have continued to be the focus of PMS operations, tracking pavement performance has been difficult. Some of the difficulties stem from the database structure of the PMS and attributes of other Caltrans databases (e.g., traffic, project construction history, as-built data), as discussed in a previous report (5). One of the more critical obstacles to tracking performance and developing performance models has resulted from Caltrans' decision to use the process of "dynamic segmentation" in conducting pavement condition surveys, as described in a previous UCPRC report (5). The details of dynamic segmentation are described in Section 1.3 of this report.

The previous report, titled "Data Mining of the Caltrans Pavement Management System (PMS) Database," which was delivered to Caltrans in 2002, documented the results of a major effort undertaken to develop pavement performance models using PMS data collected from 1978 to 1992. As part of that effort, a review was required of the capability of the historical PMS data to support pavement performance modeling. The modeling effort was only partly successful. Recommendations in that report regarding changes to the PMS structure and operation to better support pavement performance modeling included:

- Develop a new milepost system that does not break at county boundaries.
- Include structural information in the PMS database,
- Use fixed evaluation segments for the condition survey, and develop the dynamic segmentation for maintenance management through postprocessing,
- Rationalize the database structure used to store pavement-related data, including the use of more appropriate primary keys than the currently used concrete or asphalt surface types.
- Perform quality checking of the traffic database using Caltrans Weigh-In-Motion (WIM) data.
- Connect Caltrans databases with more variables that explain pavement performance to the PMS, including materials types, rehabilitation strategies, maintenance strategies, and, if possible, construction quality.

Efforts are currently under way within Caltrans to make changes of this type to the PMS. Meanwhile, a new method was developed for extracting PCS data so as to make another attempt at pulling pavement performance data from historical PMS data, meaning time histories of distress and ride quality for individual segments of pavement with consistent beginning points and end points through time. This work was done to derive performance data for analyzing pavement preservation benefits as part of Partnered Pavement Research Center Strategic Plan Element 3.2.5, described in Section 1.1, and to extract performance data for calibration of mechanistic-empirical pavement design methods as part of PPRC SPE 4.1, titled "Development of the First Version of a Mechanistic-Empirical Pavement Rehabilitation, Reconstruction, and New Pavement Design Procedure for Rigid and Flexible Pavements."

1.3. Dynamic Segmentation

A performance model that uses data collected by dynamic segmentation is problematic because it relies on data from annual pavement surveys in which sections of pavement are grouped together differently (the boundaries of the sections change) for each year. The result is that the extent of pavement distresses reported each year will fluctuate from year to year, and the data will not show the continuous, consistent deterioration of specific sections of pavement with fixed boundaries. Therefore when the time comes to analyze the database for the entire network, it will be nearly impossible to develop models for pavement performance.

Dynamic segmentation, as defined by the previous Caltrans practice, consisted of collecting data over segments with beginning and end points that changed each year depending on pavement condition. On asphalt-surfaced pavements, pavement condition surveyors performed windshield surveys and defined an observed a change in pavement type or a significant change in pavement condition as the beginning of a new segment. Once this was done, they performed a detailed survey of the first 30 m (100 ft) of the this segment, and then carried on their windshield survey until the next change in surface type or condition, which was again marked as the end of one segment and the beginning of the next. As a result of this practice, segment boundaries changed from year to year, making it very difficult to track the annual performance of a given pavement segment (6). In later years, perceived changes in different types of asphalt surface (dense-graded, open-graded, chip seals) also required that new segments be set up. By contrast, rigid pavement segments were surveyed from beginning to end. Their segment boundaries did change at times, but overall they had a greater tendency to remain constant from year to year than did the segment boundaries of pavements with asphalt surfaces.

Dynamic segmentation made annual comparisons very difficult, even with manual extraction and manipulation of the data, so changes in distress conditions and ride quality for individual pavement segments were not routinely compared from year to year.

Figure 1.1 shows an example of dynamic segmentation in the Caltrans Pavement Condition Survey (PCS) database. The year of each condition survey (from 1978 to 2004) is indicated on the vertical axis and the post miles (PM) along the roadway appear on the horizontal axis. In this sample, the roadway *segment of interest* is bounded by post miles 12.2 and 14.4, which are indicated by a continuous (red) line that does not vary from year to year. The thin horizontal lines of varying lengths show segmentation used by the PCS to survey the same length of pavement during condition surveys from 1978 to 2004. It can be seen that in some years gaps occur between PCS segments. Symbols on each line segment from 1995 to 2004 indicate the asphalt material type the PCS crew observed on the segment's surface (asphalt material type was not recorded prior to 1995).In this example section, the surface course changes from dense-graded to open-graded with time, except for the year where a segment is identified as "Emulsified Binder."

As the figure shows, boundaries for the condition survey changed little from year to year in the surveys done before 1992, which indicates that dynamic segmentation is less of a problem for this section of pavement prior to that year (as discussed in Reference [5], other parts of the network lacked this stable segmentation). The rest of the network shows similarly stable dynamic segmentation boundaries up to 1992. However, after that year the problems dynamic segmentation cause are more prevalent.

As noted, prior to 1994, pavement surface type was recorded either as rigid or flexible; in 1994 and afterward though details about the surface type for flexible pavements (DGAC, OGAC, chip seals) were recorded. However, it was discovered during the course of this study that information about the flexible pavement surface types was sometimes recorded incorrectly. Surface types in the PMS for many of the sections considered in this study therefore appear to have changed from year to year, which is unlikely and was unsupported by the condition survey data. Therefore, caution should be exercised before the information on flexible pavement surfacing type is used. Judgment should be applied before using the information on type of flexible pavement surfacing. PCS staff members noted the difficulty in identifying flexible pavement surface types by visual observation alone (7), and the established business practice was to not consult the previous year's survey.

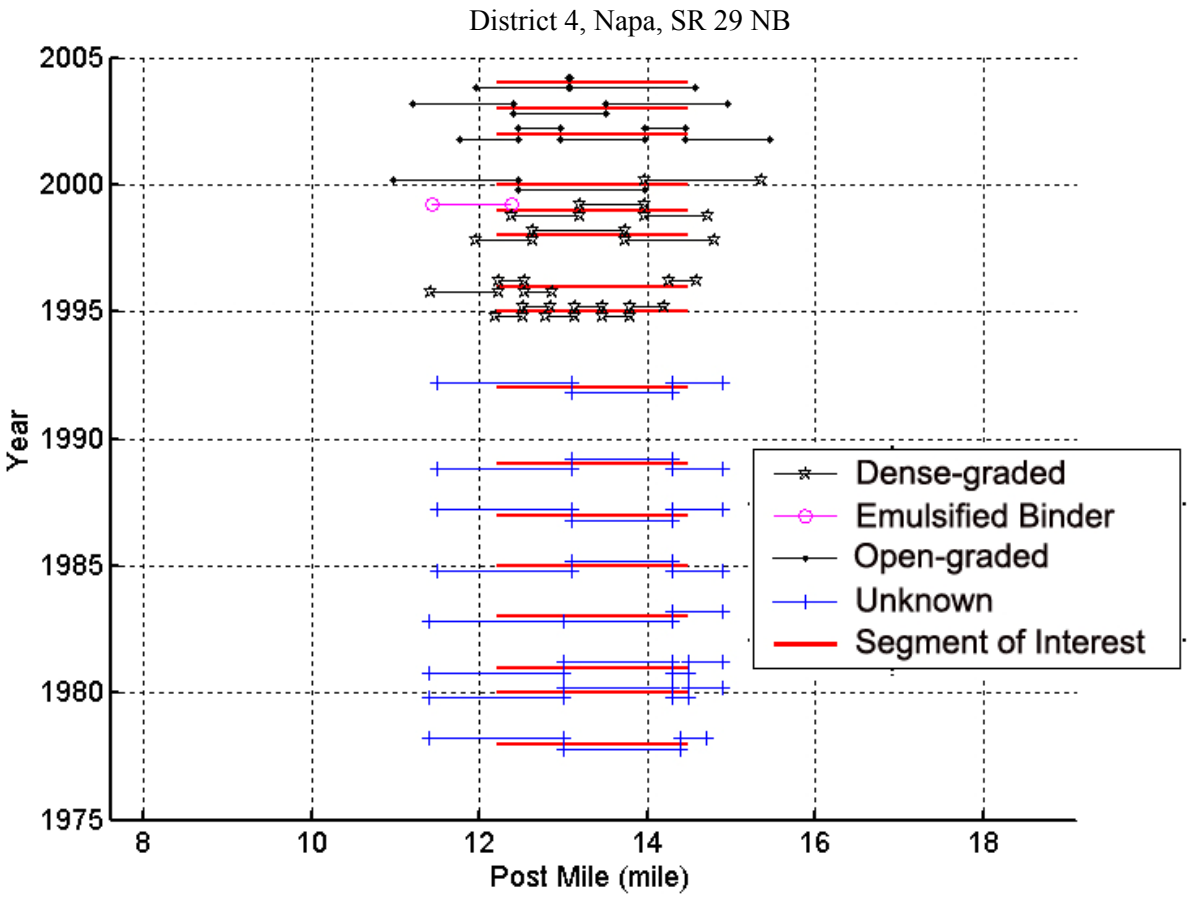

Figure 1.1: Illustration of dynamic segmentation.

As a partial remedy for this inconsistency, this project included development of an algorithm for calculating a weighted average for each distress for a fixed segment of pavement for each year; the algorithm can be used to develop more consistent trends from year to year. The weighted average is calculated using the distress surveys from all segments in the dynamic segmentation in the PCS database that overlap with the fixed segment of interest. The weighting is based on the length of each dynamic segment that overlaps the fixed segment of interest. For example, to calculate a weighted average distress for the section of interest in Figure 1.1 for 1992 and for 1995, data from three dynamic segments would be used from the 1992 survey, and data from six dynamic segments would be used from the 1995 survey.

This algorithm was used to develop time histories for various rigid and flexible pavement distresses of interest to evaluate the benefits of pavement preservation (PPRC SPE 3.2.5) and to calibrate mechanistic-empirical design models (PPRC SPE 4.1)—with varying degrees of success. This technical memorandum

documents the algorithm as well as the first examination of its use in extracting pavement performance data from the historical PMS databases.

1.4. Objectives of Work Described in This Technical Memorandum

The first and main objective of this work is to develop a methodology that enables historical pavement condition data to be extracted from the Caltrans PMS. The method must overcome, or at least partly mitigate, the confounding effects of dynamic segmentation. The ultimate purpose for developing the method is to create or validate pavement performance prediction models.

The second objective of this work is to apply the method and extract performance data. The data extracted will be used in other research projects, including validation and calibration of the following: rigid-pavement design software, a reflective cracking mechanistic-empirical model, and flexible pavement crack initiation and progression models.

1.5. Structure and Content of This Technical Memorandum

This memorandum describes efforts to extract pavement performance data from the Caltrans PMS and presents results about them. Findings from these tasks are contained in the following chapters.

- Chapter 2 describes the methodology used to extract PMS data.
- Chapter 3 presents distress data (cracking, faulting, and spalling) extracted for rigid pavements.
- Chapter 4 presents distress data (cracking) extracted for flexible pavements.
- Chapter 5 presents distress data (reflective cracking) extracted for composite pavements.
- Chapter 6 presents roughness data extracted for all pavement types.
- Chapter 7 contains observations and conclusions.

1.6. Database of Extracted Data

The database of data extracted from the PMS databases, together with plots of performance data developed using the algorithm for calculating weighted values of distress and ride quality, was delivered to Caltrans HQ Maintenance in July 2006 for data gathered for sections to be used in calibrating a mechanistic-empirical design model. An additional database, showing the same type of data extracted for sections used in analyzing pavement preservation benefits, will be delivered to Caltrans with the Stage 2 draft of this technical memorandum.

2. METHODOLOGY

This chapter describes the methodology developed for extracting historical pavement data from the Caltrans PMS. Developing the methodology met the first project objective. Results obtained from applying the methodology (the second objective) are described in subsequent chapters.

2.1. Previous Attempts—Top-Down Approach

Attempts were made previously to convert the dynamic segments to fixed segments for the entire network by writing software codes in a *top-down* approach. The details of the efforts are documented in a report by Lea et al. (5) In the *top-down* approach, the entire PMS database from 1978 to 1992 was cleaned and sorted using various algorithms to convert dynamic segments to fixed segments and apply formal relational database rules to the database. This process resulted in discarding a large portion of the data. As a result of insights from the previous attempt, a different, *bottom-up* approach was developed to resolve the problem. The top-down approach did not work well because Caltrans construction project history files are not organized and available to enable computer sorts that tell what type of work was done, where on the pavement it was done, and when it was done for the entire network.

2.2. Current Approach—Bottom-Up Method

In the top-down approach applied in earlier efforts, attempts were made to convert dynamic segments to fixed segments or to identify fixed segments in the PMS on a network level. However, in the bottom-up approach, individual "sections of interest" are identified and used to track the years of data in the PMS. The sections are identified as being of interest because original project information on construction, rehabilitation, or maintenance was found for that section of pavement, and therefore the performance of that original pavement, rehabilitation, or maintenance treatment is to be tracked. The construction information, consisting of when the work was done, what was done, and when it was done, is needed to be able to explain changes in distress and ride quality. Lack of such information in a relational database that could be linked to the PCS database was the major reason that the top-down approach was not very successful.

As described in Chapter 1, referencing Figure 1.1, the segment of interest will be part of different Caltrans segments surveyed each year. An algorithm was developed to average the distresses from the Caltrans segments that encompass that section of interest.

Note that for the remainder of this report the dynamic segments are referred to as "Caltrans PCS segments" and the fixed segments are referred to as "UCPRC segments."

As developed, the algorithm reports a *weighted average* of the following measured parameters for the fixed segment of interest:

Flexible Pavement Cracking: Alligator A cracks (AAC, percentage of wheelpath cracked), Alligator B cracks (ABC, percent of wheelpath cracked). These distresses are currently, and have always been, measured by visual observation, and the percentage of wheelpath cracked has been measured by crews pacing the distress length in the first 100 ft of each segment.

Rigid Pavement Cracking: First-Stage Cracking (FSC, percentage of slabs cracked), Third-Stage Cracking (TSC, percentage of slabs cracked), Percent Corner Cracking (PCC, percentage of slabs cracked). These distresses have always been measured by visual observation of each slab in a segment.

Ride/Roughness: Ride Score (RDS) and the *average* of IRI from Caltrans segments found within the margins of the project. Ride Score was calculated from Mays Meter measurements from 1978 to 1992. A Mays Meter is a response-type system for measuring road roughness (see Reference [8] for more information). Since 1997 ride quality has been measured in terms of the IRI using inertial profilometers. No roughness measurements were taken from 1993 through 1996.

The weighted average algorithm could not be used for the following two parameters: faulting in rigid pavements, and rutting in flexible pavements. Unlike the previous parameters, these parameters are not measured on a continuous scale, but instead are recorded as being either present or not present. These distresses were not measured for severity in terms of fault height or rut depth. Instead, the surveyor visually observed whether they were present or not. The threshold for being present is not well-documented for some years, but had to be large enough (currently a visual estimation of being ¾ inch or more for rutting) to be identified (for rutting) by the surveyor by eye from the side of the road for rutting, and (for faulting) from inside a van moving along the shoulder of the road.

For each of these two distresses, the decision was made to aggregate the values from the dynamic Caltrans PCS segments that fell within the boundaries of the fixed UCPRC segment and to report them in binary format: YES if faulting or rutting present, and NO if no faulting or rutting . An example of the rule applied was that if at least one Caltrans PCS segment within a fixed UCPRC segment had faulting present, then the entire UCPRC section was considered as having faulting—that is, the binary indicator

for faulting was set to YES. If none of the Caltrans segments within a UCPRC segment had faulting, then the entire UCPRC segment was considered as not having faulting, hence binary indicator set to NO.

The formula used to calculate the weighted averages was:

Weighted Average % wheelpath cracked or % slabs cracked =

$$(\sum_{i}^{n}(distressi * CTsegmi_length)/(\sum_{i}^{n} CTsegmi_length) \quad \textbf{(1)}$$

where: distressi = measured value of cracking for a Caltrans PCS segment;
n = sequence of the Caltrans segments within project's margins; and
CTsegmi_length = the length of the Caltrans segment for which distress was reported within the project's boundaries.

Within one UCPRC segment, at least one, two, or three of the four scenarios described below can take place with regard to the overlapping of the Caltrans and UCPRC segments. Under four scenarios (described below), data from a Caltrans segment will be included in the weighted average. For each Caltrans segment that overlaps the UCPRC section, the overlapping length is calculated and used as the weighting factor in the weighted average for a particular segment. If scenario 4 takes place, then the UCPRC section's weighted average is the actual value of the surveyed Caltrans segment.

This algorithm basically says that the extent of the distress in the UCPRC segment was calculated using a weighted average of the distress extents in the Caltrans segments that overlapped the UCPRC segment in each year. The weighted average was calculated from the overlapping length of each Caltrans segment on the UCPRC segment.

The four scenarios are described below. The terms used in these scenarios are:

PMSEND	=	End Post Mile of Caltrans PCS segment
PMSBEG	=	Start Post Mile of Caltrans PCS segment
CLBEG	=	Start Post Mile of construction project segment (called "UCPRC segment")
CLEND	=	End Post Mile of construction project segment (called "UCPRC segment")

The four scenarios are presented graphically in Figures 2.1 through 2.4. In each of these figures, the red line indicates the Caltrans PCS segment and the blue line indicates the UCPRC segment. The dashed lines in Figure 2.1 show the overlap between the two segments; this overlap needs to be greater than 10 percent for the Caltrans segment to be included in the UCPRC segment weighted average. In Figure 2.2 a single dashed line shows the overlap between the two segments; the single line is used to indicate that the Caltrans segment is always in included in the UCPRC segment weighted average. The reasons for this are discussed below.

Scenario 1: The Caltrans PCS segment starts outside the UCPRC segment but ends within it, with the condition that the overlapping length is greater than 10 percent of the UCPRC segment, as expressed in the following equation:

$$(PMSEND - CLBEG) >= 0.1*(CLEND - CLBEG) \quad \textbf{(2)}$$

The reason for including a minimum 10 percent overlap in the weighting is that Caltrans PCS flexible pavement data are collected on the first 100 ft of each Caltrans segment only, and therefore if there is less than 10 percent overlap with the end of the Caltrans section the distresses are probably not relevant to the UCPRC segment.

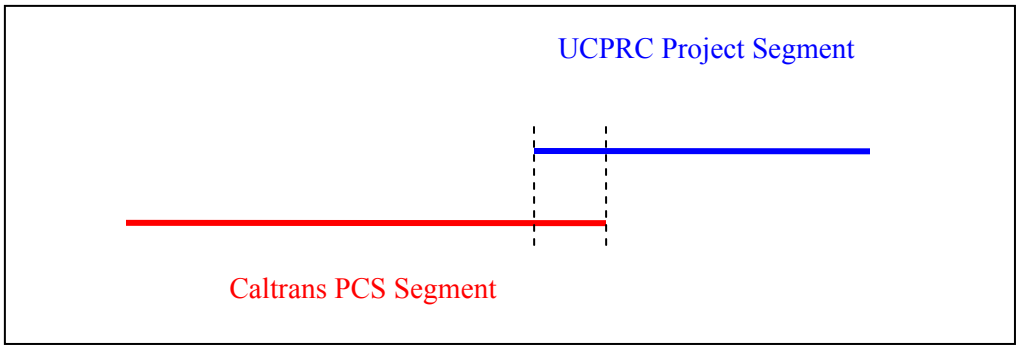

Figure 2.1: Scenario 1.

Scenario 2: The Caltrans segment starts within the UCPRC segment, as expressed by the following equation:

$$PMSBEG \geq CLBEG \quad \textbf{(3)}$$

The reason for not requiring a minimum 10 percent overlap in the weighting is that Caltrans PCS flexible pavement data are collected on the first 100 ft of each Caltrans segment, and therefore the first part of the Caltrans segment is the most relevant information pertaining to the preceding UCPRC segment.

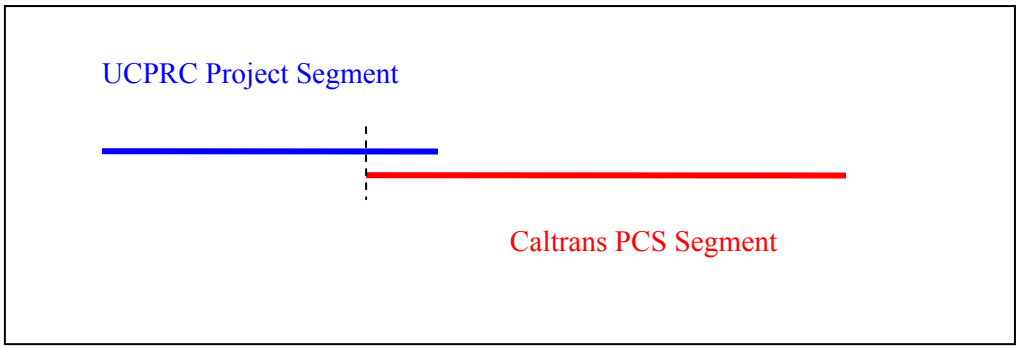

Figure 2.2: Scenario 2.

Scenario 3: The Caltrans segment runs the entire length of the UCPRC project segment, as expressed by the following equation:

$$(PMSBEG \leq CLBEG) \text{ AND } (PMSEND \geq CLEND) \quad \textbf{(4)}$$

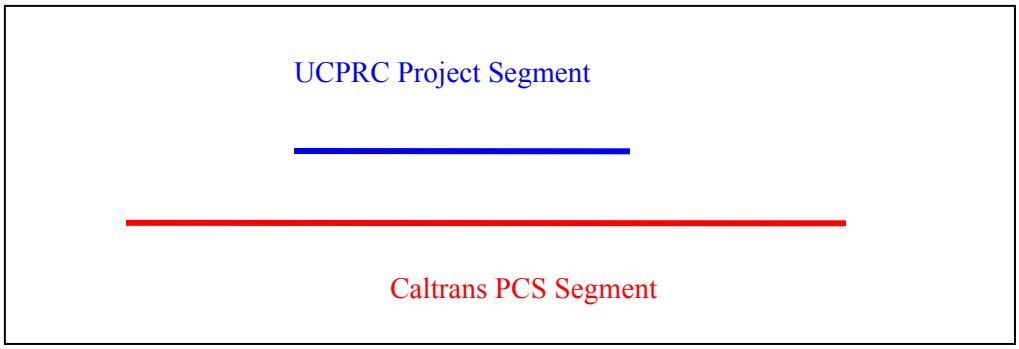

Figure 2.3: Scenario 3.

Scenario 4: The Caltrans segment lies within the boundaries of the UCPRC project segment, as expressed by the following equation:

$$(PMSBEG \geq CLBEG) \text{ AND } (PMSEND \leq CLEND) \quad \textbf{(5)}$$

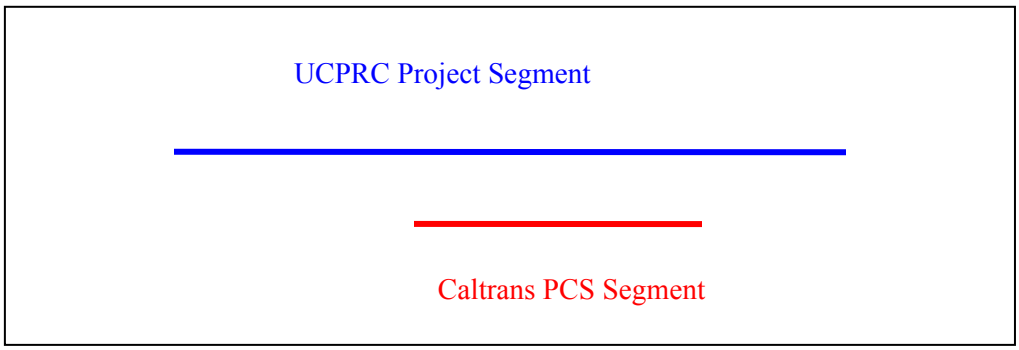

Figure 2.4: Scenario 4.

2.3. Data Extraction Process and Databases Used

The algorithm discussed in the previous section was applied to extracted data from the PMS to be used for various research purposes. The research purposes are stated below, and details of the section for which PMS data were extracted will be discussed in the subsequent chapters:

- Pavement preservation benefit analysis: flexible pavement performance data were gathered from 718 projects for which maintenance and rehabilitation construction histories had been gathered from Caltrans Districts and the personal databases of HQ Maintenance regional coordinators.
- Mechanistic-empirical pavement design calibration:
    - Rigid pavement performance data from 46 sections were extracted and will be used for validation and calibration of rigid module of NCHRP 1-37a (Mechanistic-Empirical Pavement Design Guide, MEPDG) software.

  - Performance data from 53 crack, seat, and overlay (CSOL) sections were extracted and will be used for validation and calibration of the rigid module of the NCHRP 1-37a software and a reflective cracking model of *CalME* being developed by the UCPRC.
- Performance model calibration: Performance data from 78 sections of AC overlay on underlying flexible pavement were extracted and will be used for validation and calibration of a crack initiation model and validation of a crack progression model, both of which were developed using Washington State PMS data (9).

The results presented in the remainder of this technical memorandum are from data extracted for the latter two purposes, the ME design model calibration and performance model calibration. These datasets were where the algorithm was first used.

As mentioned in Section 1.6 of this technical memorandum, extracted PMS data (i.e., distress plots) for all ME design calibration and pavement performance modeling sections are on the CD that was given to the Caltrans HQ Division of Maintenance in July 2006. Structural information for all the rigid and CSOL sections is available from field coring. Structural information for 78 sections of AC overlay on underlying flexible pavements is obtained from field sampling and/or from GPR measurements (10).

Extracted PMS data for all pavement preservation analysis sites will be delivered to Caltrans with the Stage 2 draft of this memorandum. No pavement structure information was available for those sites, as is discussed in Reference (11).

Pavement performance data were extracted from the Caltrans PMS that had condition surveys between 1978 and 2004. Caltrans has recorded its PMS in three differently formatted databases and changed the ways they recorded distresses between 1978 and 2004. The three databases are for the years 1978 to 1992, 1992 to 1997, and 1997 to 2004. Information about the differences in the three databases is not discussed in this technical memorandum. However, issues about the first two databases are listed in a report by Lea and Harvey (5). The Caltrans PMS was first populated in 1978, and 2004 is the last year for which data were available to the UCPRC at the time of this writing.

3. RIGID PAVEMENT DATABASES

Distresses recorded for rigid pavements in the PMS are first-stage cracking, third-stage cracking, corner cracking, faulting, and roughness. Data were extracted for 46 sections. The data will help in validation and calibration of the rigid module of the MEPDG. To validate the models in MEPDG, it is essential to have information about the progression of distresses with time. The distribution of the sections according to the route is shown in Table 3.1. Table 3.2 shows the list of 53 CSOL sections for which PMS data were extracted. The composite sections were identified as rigid pavements before CSOL rehabilitation. Different segments within each section of highway have different lengths, depending on the length of the new construction, rehabilitation or maintenance projects, or subsections of projects, being tracked.

Table 3.1: Rigid Pavement Sections for Which PMS Data Were Extracted

Route	Direction	District	County	Number of UCPRC Segments	Starting PM	Ending PM
80	E	4	Solano	10	18.46	35.23
80	W	4	Solano	1	36.58	36.69
85	N	4	Santa Clara	5	13.9	15.17
85	S	4	Santa Clara	5	13.52	15.42
101	N	4	Sonoma	4	50.52	52.94
101	S	4	Sonoma	5	50.84	53.02
86	E	11	Imperial	1	31.71	31.82
86	W	11	Imperial	4	29.45	33.08
10	E	8	Riverside	5	13.29	15.83
15	N	11	San Diego	5	10.30	14.25
15	S	11	San Diego	1	17.03	17.13

Table 3.2: Composite Pavement Sections for Which PMS Data Were Extracted

Route	Direction	District	County	Number of UCPRC Segments	Starting PM	Ending PM
5	NB	2	Shasta	9	29.17	39.9
5	SB	2	Shasta	5	28.9	31.7
101	N	5	Santa Barbara	23	21.18	83.9
58	W	6	Kern	6	70.89	75.87
580	E	10	San Joaquin	5	5.02	8.88
580	W	10	San Joaquin	5	5.35	8.70

Pavement condition data extracted include first-stage cracking, third-stage cracking, corner cracking, faulting, and roughness. First-stage cracking, third-stage cracking, and corner cracking are recorded as a

percentage of slabs cracked. Faulting was measured differently during various time periods in the PMS and is described below:

1. 1978 to 1992: Faulting was rated as "0," "1," or "2." No clear information was found regarding the severity of faulting represented by each of the three categories, so it was assumed that "0" means "no faulting," "1" means "light-to-moderate faulting," and "2" means "moderate-to-severe faulting."
2. 1992 to 1997: Faulting was recorded as "F" or "T," meaning either "false" (no faulting) or "true" (faulting present).
3. 1998 to 2004: Faulting was recorded as "0" or "-1." It was assumed that "0" means no faulting and "–1" means faulting.

Throughout the PMS history, fault measurements were subjective and recorded as a categorical variable, meaning that it was text, not a number. For the purpose of data extraction, all the fault measurements were converted into binary format. If there were indications of faulting (either moderate or severe), the previous ratings were converted to "1," and if there were no indications of faulting the previous ratings were converted to "0."

Roughness was measured as ride score from 1978 to 1992, and as International Roughness Index (IRI, in/mile) from 1996 to 2004. Very little roughness data are available from 1992 to 1997. Details regarding ride score measurements can be found in the report by Boucher (6).

3.1. First-Stage Cracking Data

Plotting the first-stage cracking percentages recorded in the PMS showed, for many sections, a discernible start of first-stage cracking, subsequent increases as cracking progressed, and decreases that may have resulted from maintenance or rehabilitation activities. All the sections studied provided data showing reasonable values and trends. Example plots from applying the weighting algorithm to first-stage cracking data extracted from the PMS are shown in Figures 3.1 through 3.5 and are discussed below. The plots show first-stage cracking (recorded as a percentage of slabs cracked) over the time period in the PMS database.

Figures 3.1 and 3.2 show first-stage cracking recorded on eastbound Interstate 80 (I-80 EB). Lane definitions follow Caltrans practice, with Lane 1 being on the inside median and lane numbers increasing moving toward the outside shoulder. The upper two lines in Figure 3.1 show overall trends of increasing

crack progression for the outer two lanes. Cracking in Lane 4 was consistently higher than in Lane 3. It can be seen that 1997 first-stage cracking appears to be zero percent for Lane 3. A plausible explanation for this could be that data were not recorded for that particular year. During the course of the data extraction exercise, in many instances it was observed that a "0" value for a particular distress type in the PMS could mean one or both of two things:

1. No data were recorded that year.
2. There was no distress present.

Judgment should be applied before inferring anything about "0" values in the PMS database. In this case, looking at the overall trend in the cracking it was inferred that no data were recorded in 1997. Lane 2 follows the same trend until 1987, and then drops below 5 percent. As expected, Lane 1, which would be expected to carry the least truck traffic, consistently shows very low cracking.

Applying the weighting algorithm on other sections produced less-distinct patterns. For example, Figure 3.2 again shows crack progression in the outer two lanes (3 and 4) but large variation (at least 10 percent from one year to the next) in cracking recorded from 1996 through 2003. The cause of this variation is unknown. Cracking recorded for Lane 2 is consistently highest of all lanes until 1992. A plausible explanation for this is that Lanes 3 and 4 might have been added many years after Lanes 1 and 2 were constructed. After several years of no data, cracking is recorded as zero percent in 1996 and subsequent years, suggesting that either major maintenance or rehabilitation had been performed. A lack of historical records of maintenance activities prevents identifying the type of work done. Cracking in Lane 1 stayed below 5 percent throughout.

Figure 3.3 shows that first-stage cracking data for southbound US 101 started in 1998. Before 1998 the PMS database recorded distresses on flexible pavement (not shown in this figure), which suggests that this section of US 101 was either reconstructed or realigned as a rigid pavement in 1998.

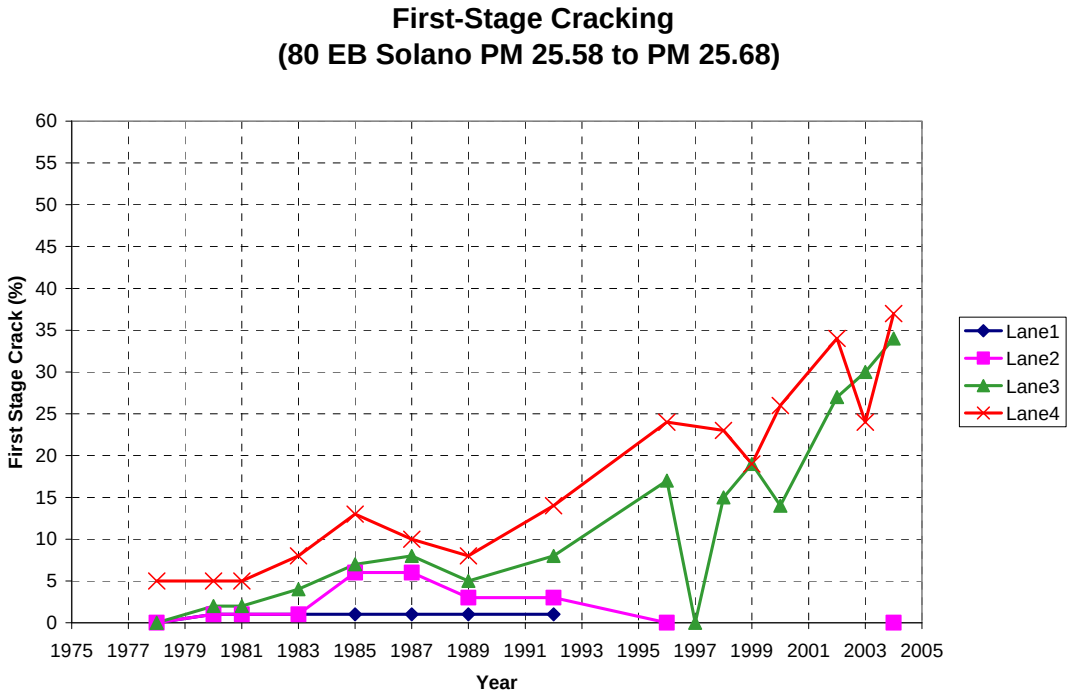

Figure 3.1: First-stage cracking on I-80 EB, Solano, PM 25.58 to PM 25.68.

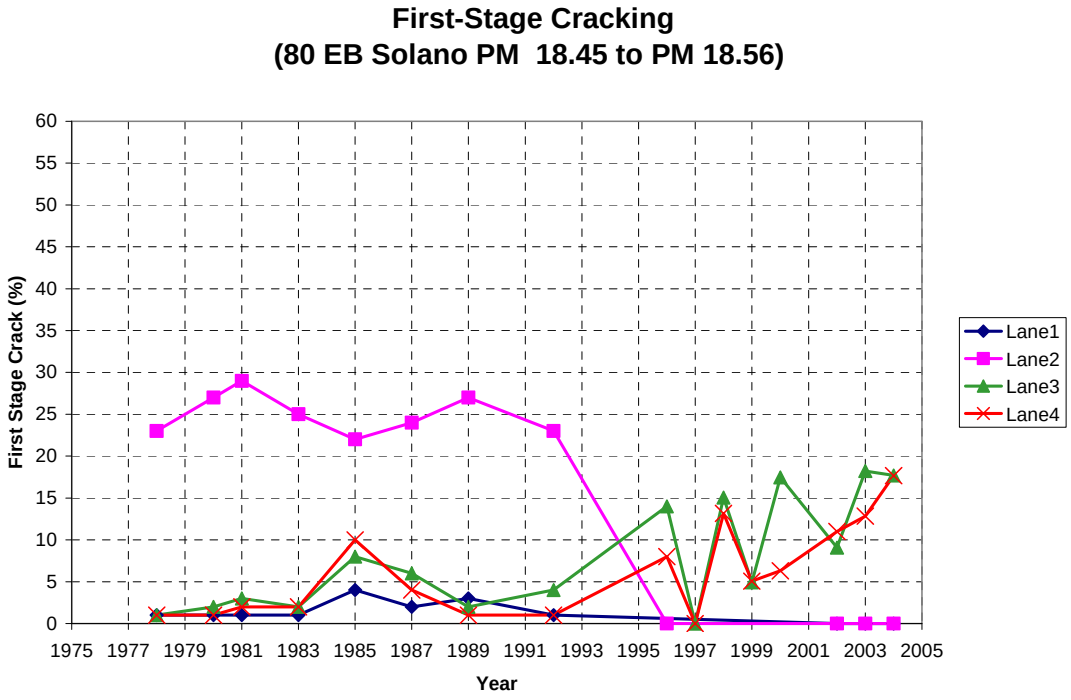

Figure 3.2: First-stage cracking on I-80 EB, Solano, PM 18.45 to PM 18.56.

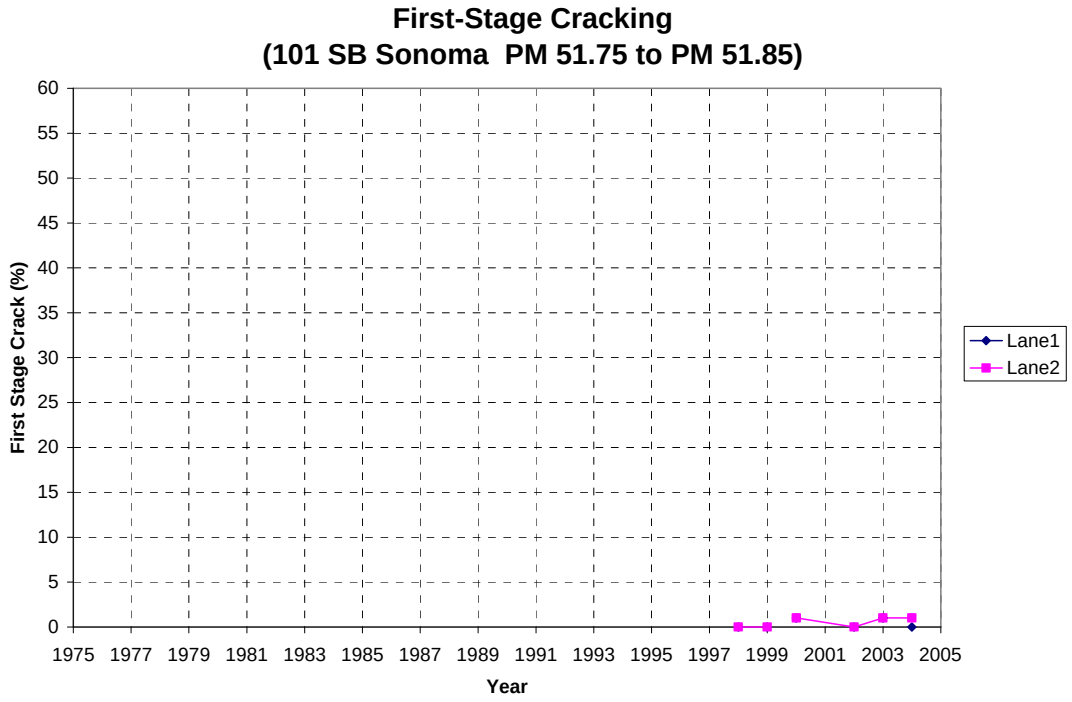

Figure 3.3: First-stage cracking on US 101 SB, Sonoma, PM 51.75 to PM 51.85.

Figure 3.4 shows first-stage cracking on eastbound I-10 in Riverside County. Cracking in Lane 4 is higher than other lanes, as expected, because that lane would ordinarily carry the most trucks and overall shows crack progression. However, cracking varies widely (up to 20 percent from one year to the next from 1997 to 2004). Cracking is recorded as zero percent in 1994, dropping nearly 15 percent from the previous survey recorded in 1992. Cracking is not recorded again until 1997, when the level jumps to a level nearly to that recorded in 1992. The levels and variability could have several causes or contributing factors, including the following:

1. Dynamic segmentation may not have been addressed adequately by the algorithm in this case. This seems unlikely, based on the original PMS segment boundaries (which were generally consistent) over which the condition survey was performed.
2. First-stage cracking may have progressed to third-stage. This is ruled out because the PMS data show separate third-stage cracking data (see Figure 3.10) that differ from those in Figure 3.4.
3. Operational factors, e.g., changes in field survey personnel, may have contributed. This possibility is unknown, its potential effects are uncertain, and the facts would be difficult to discern.
4. Partial slab replacement or major maintenance may have been performed. Maintenance records are not available to confirm this possibility.

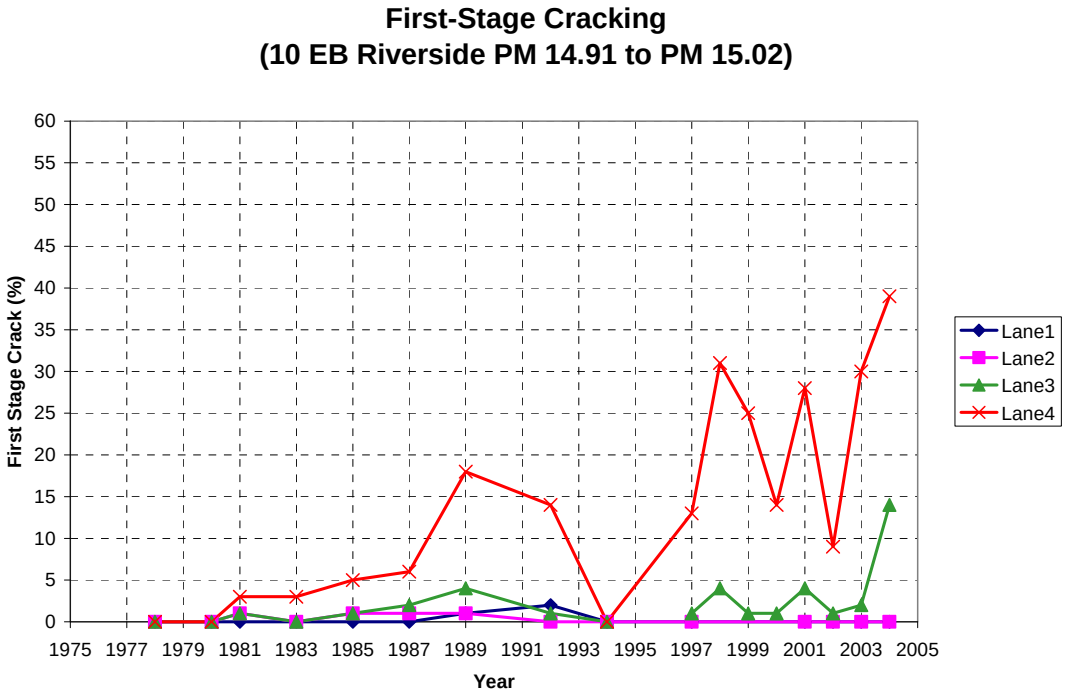

Figure 3.4: First-stage cracking on I-10 EB, Riverside, PM 14.91 to PM 15.02.

Figure 3.5 shows first-stage cracking on southbound I-15 in San Diego County. Cracking stays below 5 percent in all lanes. Remaining sections on the same route in a northbound direction show that the pavements were flexible before 1981/1983 because of the distress types recorded at that time. After 1981/1983 rigid pavement distresses were recorded, suggesting that the route was realigned or reconstructed. There was not much cracking (first stage, third stage, or corner) on all the sites.

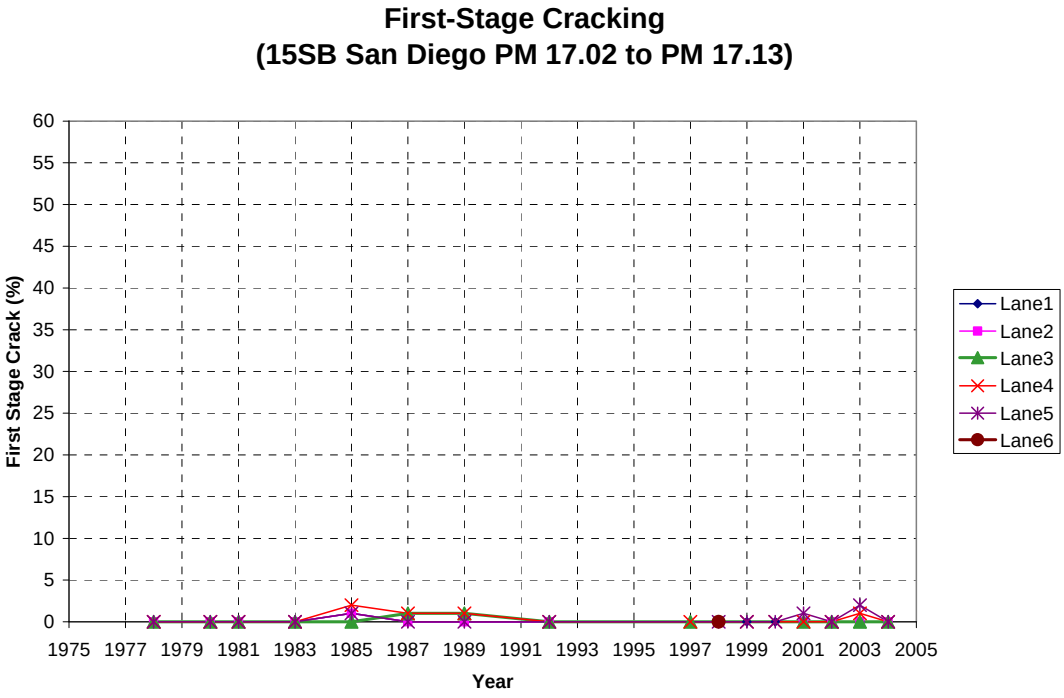

Figure 3.5: First-stage cracking on I-15 SB, San Diego, PM 17.02 to PM 17.13.

3.2. Third-Stage Cracking

Plotting the third-stage cracking percentages recorded in the PMS for some sections showed a discernible start of third-stage cracking, subsequent increases as cracking progressed, and decreases that may have resulted from maintenance or rehabilitation activities. Some sections had no third-stage cracking, but many had cracking in magnitudes much smaller than first-stage cracking, which is reasonable. Examples of results from applying the weighting algorithm to third-stage cracking data extracted from the PMS are shown in plots in Figures 3.6 through 3.10 and are discussed below.

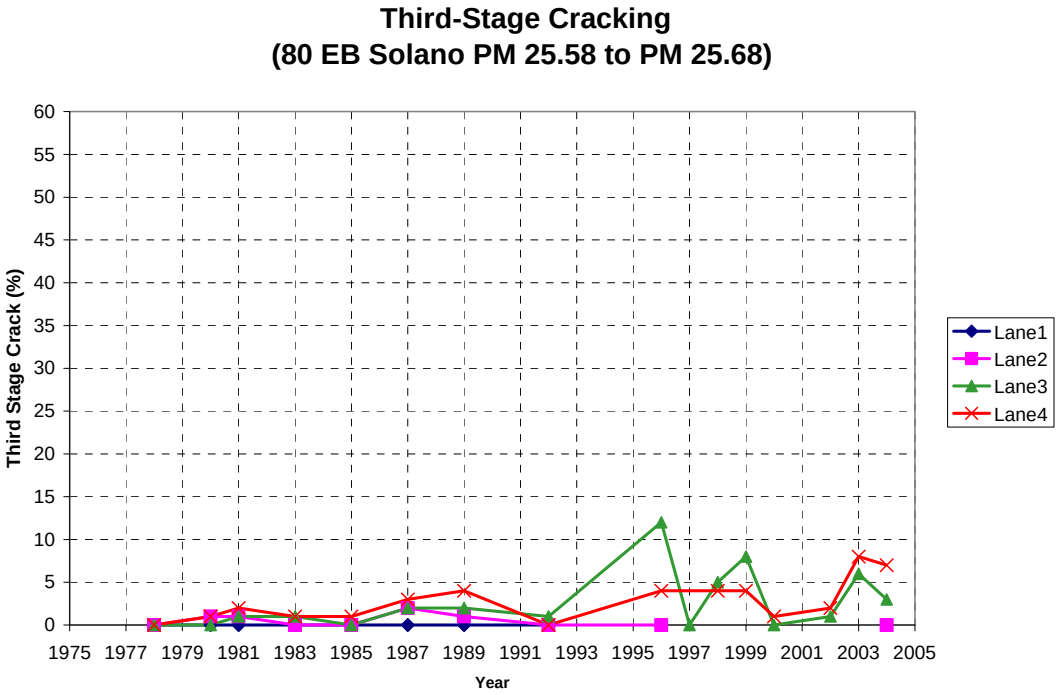

Figure 3.6: Third-stage cracking for I-80 EB, Solano, PM 25.58 to PM 25.68.

In Figure 3.6 the magnitude of cracking is generally low for all lanes. Data for Lane 3 show an overall trend of increasing cracking. Third-stage cracking data in Figure 3.6 can be compared with values for first-stage cracking for this same pavement section, shown in Figure 3.1. Visual inspection of the PMS data for Lane 4 shows a lack of correlation of third-stage and first-stage cracking. As expected, third-stage values are lower than those for first stage, since first-stage cracking develops first. The overall trend for third-stage cracking in Lane 4 shows a gradual increase, whereas first-stage cracking increases rapidly. Intervals where first-stage cracking dropped in Lane 4 (1985 to 1989, 1996 to 1999, and 2002 to 2003) do show a small increase in the third-stage cracking, indicating that first-stage cracks are being converted to third-stage cracks.

Third-stage cracking recorded for another section of eastbound I-80 is shown in Figure 3.7. Cracking is below 5 percent always in Lanes 1 and 2, and below 5 percent for most field surveys on Lanes 3 and 4. Overall, the trend is toward an increase in third-stage cracking, as expected. However, the extracted data show unexplained fluctuations, especially since 1996.

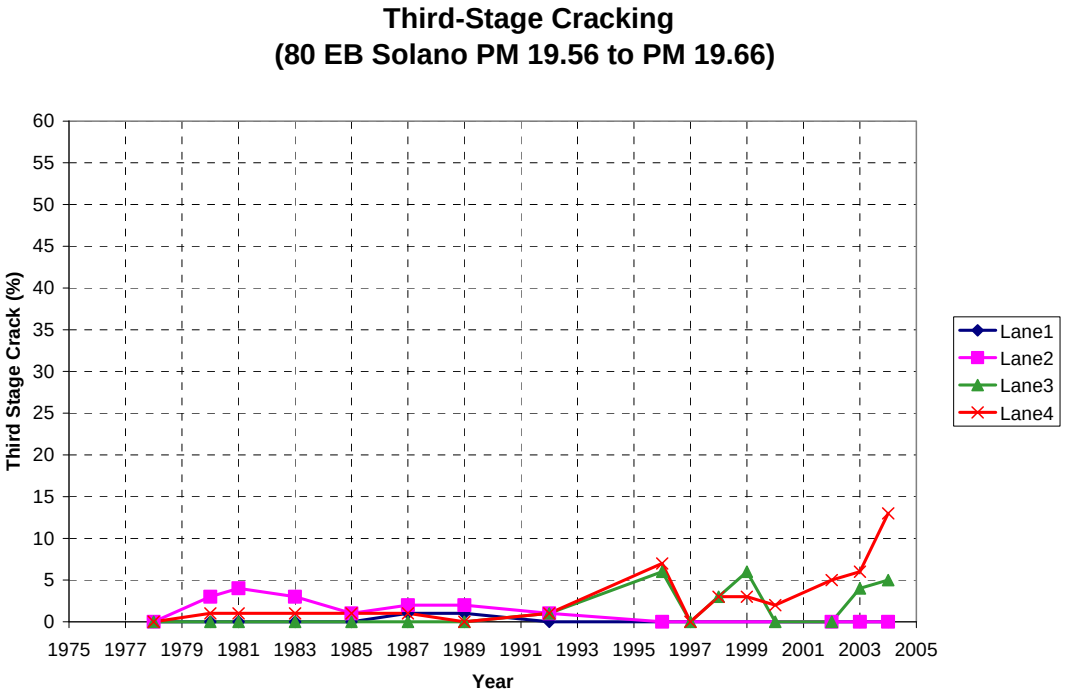

Figure 3.7: Third-stage cracking for I-80 EB, Solano, PM 19.56 to PM 19.66.

Figure 3.8 shows a section where a high percentage of third-stage cracking was recorded (Lane 3). For comparison, the corresponding first-stage cracking for this site is shown in Figure 3.9. The drop to zero percent first- and third-stage cracking in 1997 is unexplained but may indicate that the section was not rated that year. Overall, the figures show crack initiation, crack progression,, and reasonable correlation of first- and third-stage cracking trends, with first-stage cracking leading third-stage cracking over time.

Third-stage cracking data in Figure 3.10 can be compared with values for first-stage cracking for this same pavement section shown in Figure 3.4. Again, both cracking types show crack initiation and trends of increasing cracking that indicate crack progression, and values of first-stage cracking were recorded as higher than third-stage cracking. Visual assessment of the PMS data for Lane 4 shows an overall strong correlation of cracking: third-stage cracking values drop (1992 to 1994, 1998 to 2000, and 2001 to 2002) and rise (1994 to 1998, 2000 to 2001, and 2002 to 2004) at the same times as first-stage cracking. Cracking data for other lanes do not show trends as discernible as for Lane 4.

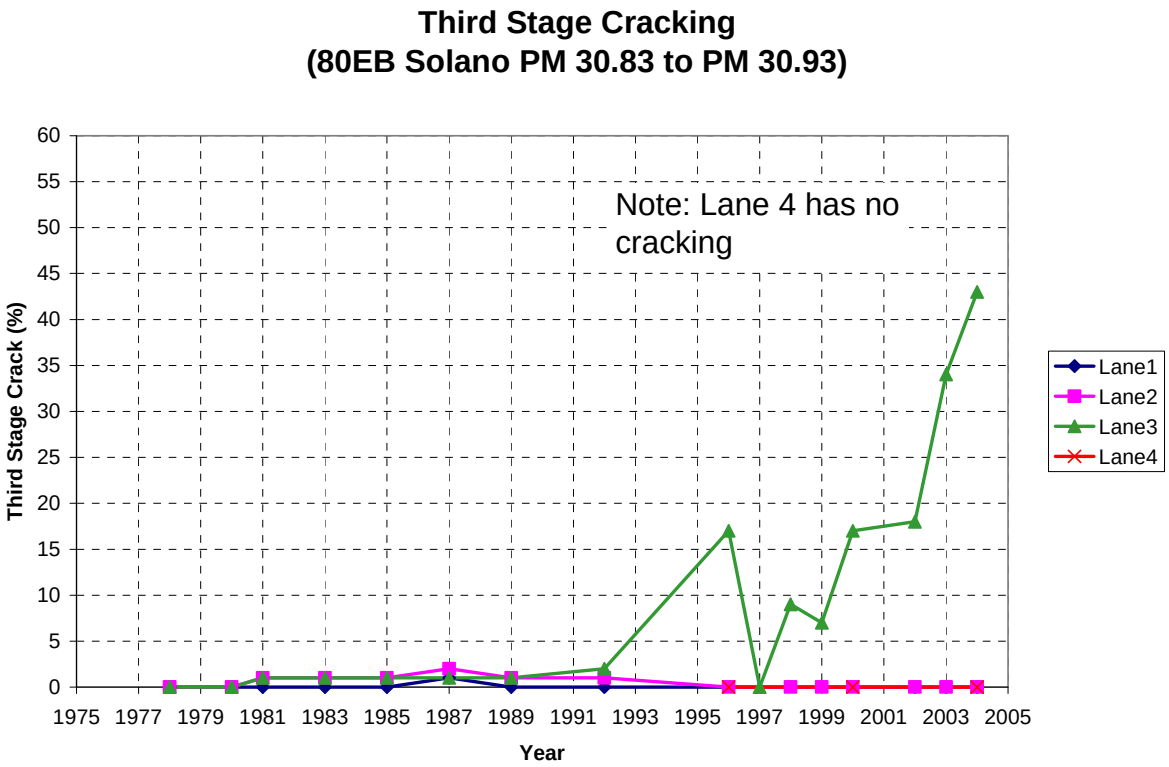

Figure 3.8: Third-stage cracking for I-80 EB, Solano, PM 30.83 to PM 30.93.

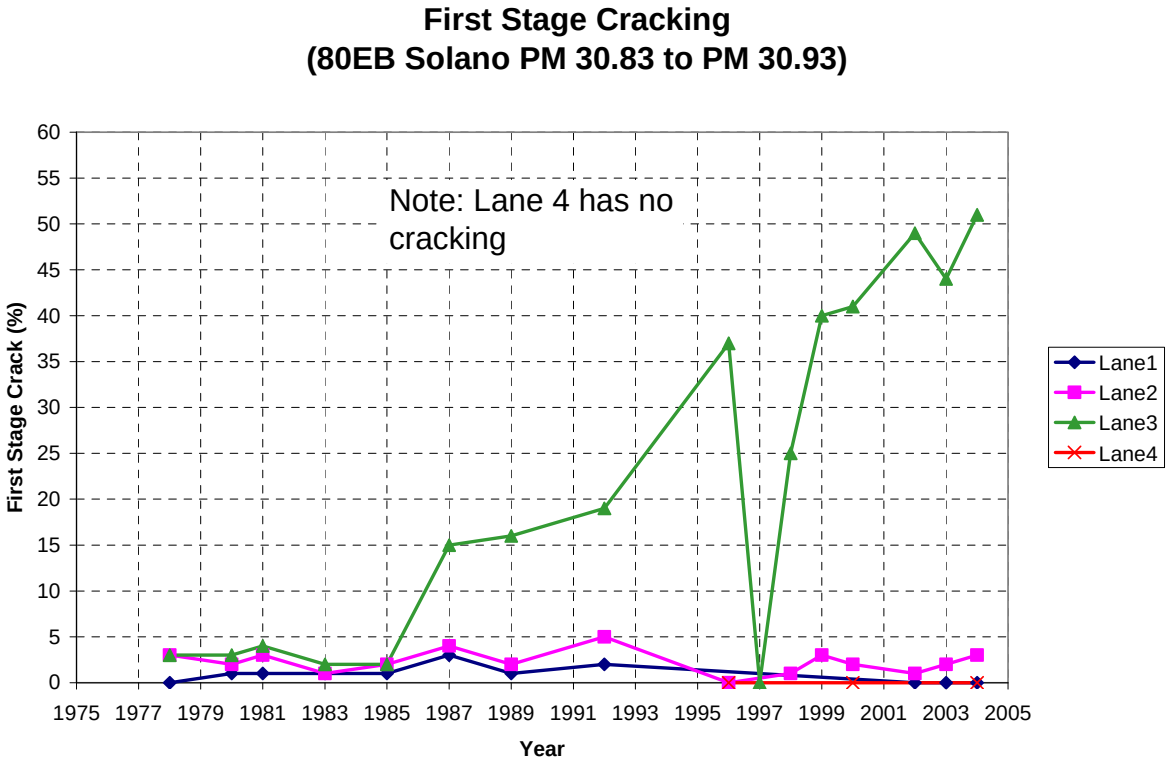

Figure 3.9: First-stage cracking on I-80, corresponding to the case shown in Figure 3.8.

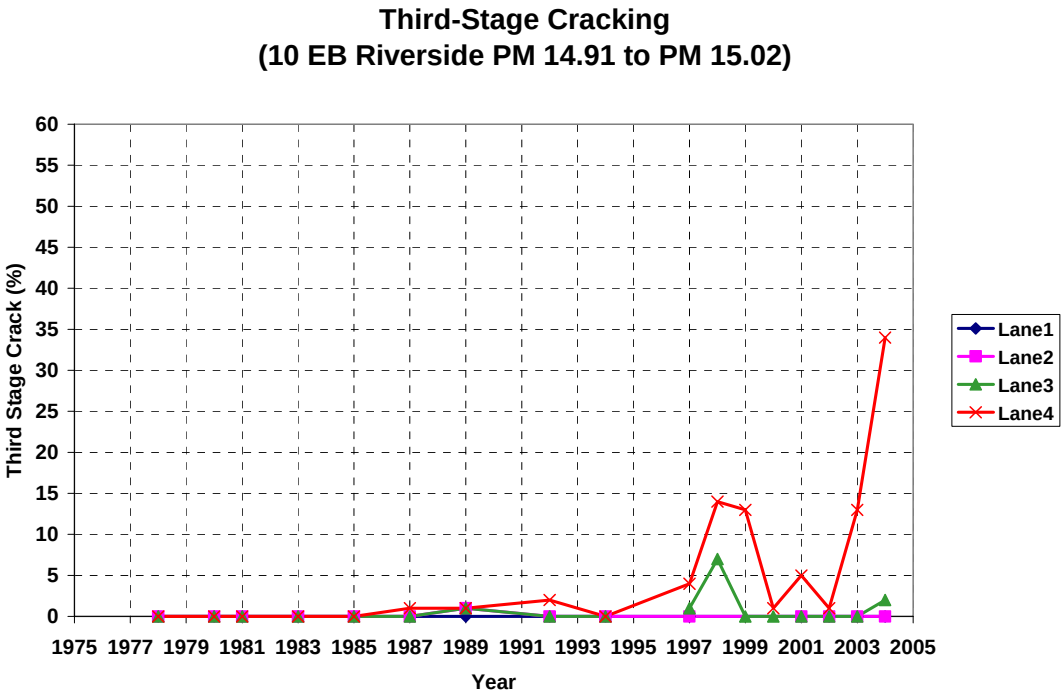

Figure 3.10: Third-stage cracking corresponding to I-10 EB, Riverside, PM 14.91 to PM 15.02.

3.3. Corner Cracking

Plotting the corner cracking percentages recorded in the PMS for some sections showed the start of corner cracking, subsequent increases in cracking, and decreases that may have resulted from maintenance or rehabilitation activities. Examples of results from applying the weighting algorithm to corner cracking data extracted from the PMS are shown in Figures 3.11 and 3.12.

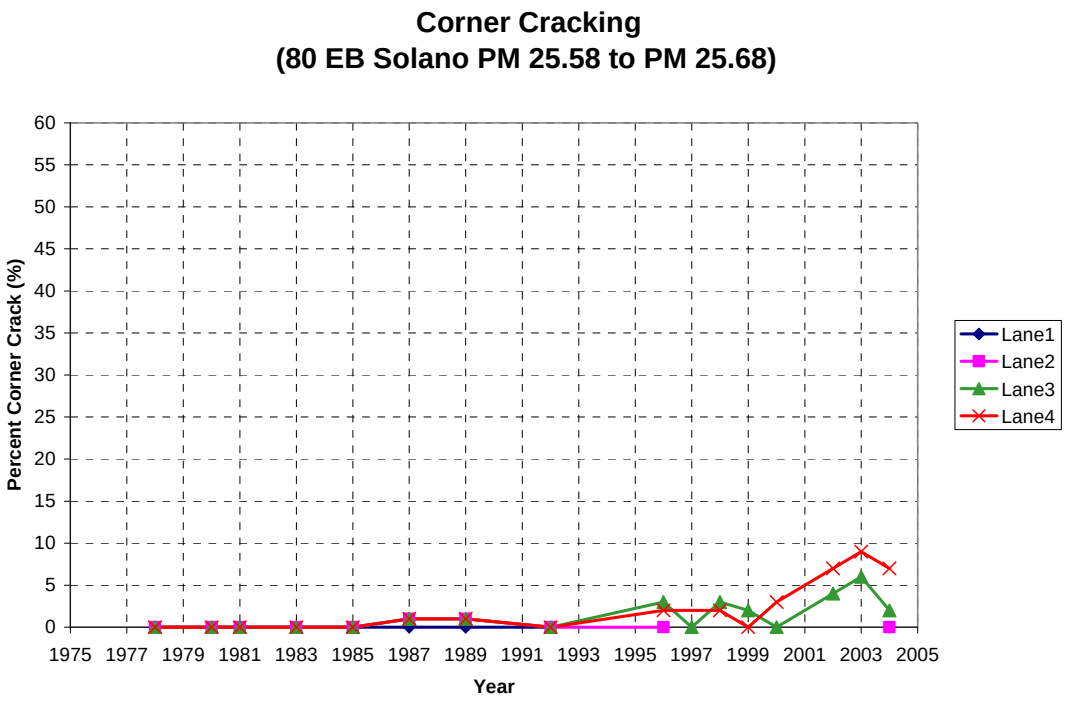

Figure 3.11: Corner cracking for I-80 EB, Solano, PM 25.58 to PM 25.68.

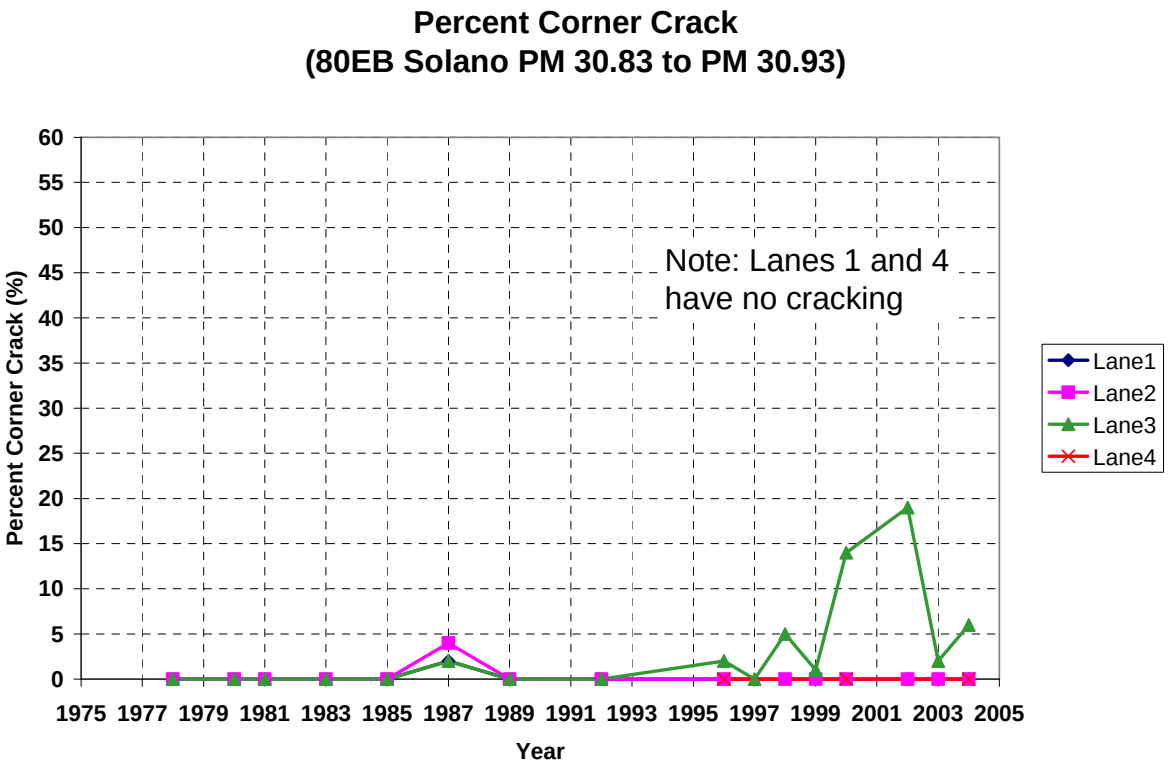

Figure 3.12: Corner cracking for I-80 EB, Solano, PM 30.83 to PM 30.93.

3.4. Faulting

As explained at the start of Section 3, faulting is recorded as a categorical variable (text as opposed to a number) in the PMS, which was then converted into binary format for the purpose of data extraction. Examples of the extracted faulting data are presented in Figures 3.13 and 3.14. Reviewing both figures conveys the difficulty in discerning meaningful information from the extracted PMS faulting data. Drawing inferences about faulting may be possible by evaluating roughness data in the PMS, because roughness is controlled mainly by faulting. The reasonableness of the roughness data in the PMS is discussed later. The algorithm did not work for faulting because of the nature of the faulting data (which were rated in categories instead of measuring the actual fault heights), though the algorithm may help draw inferences about faulting based on roughness data, provided that valid roughness data exist.

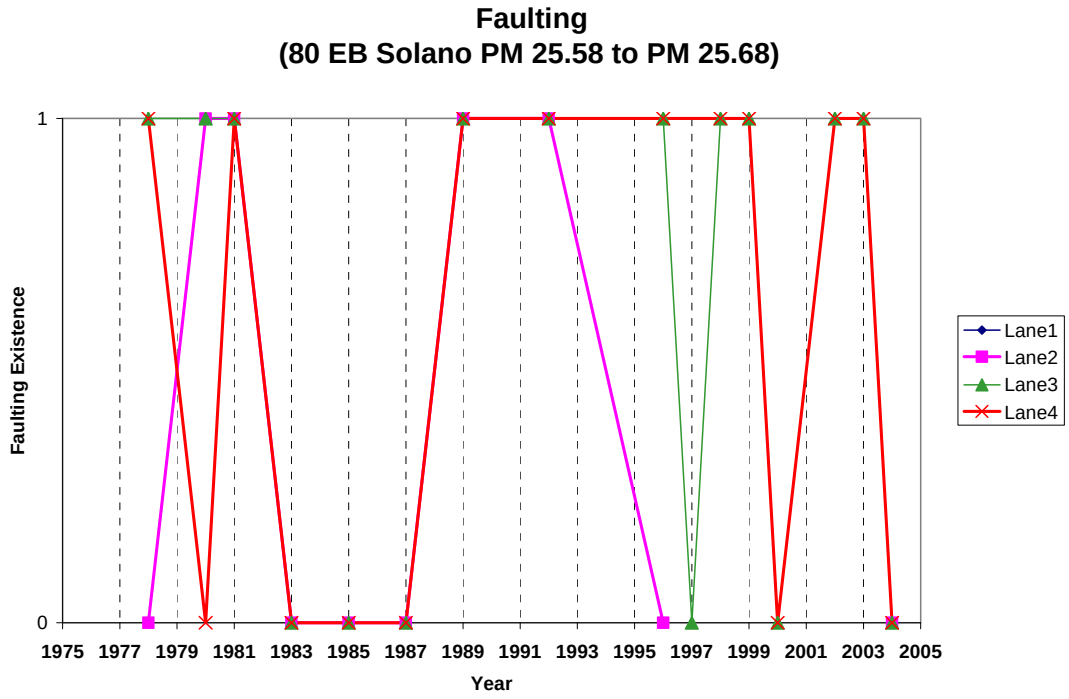

Figure 3.13: Faulting for I-80 EB, Solano, PM 25.58 to PM 25.68.

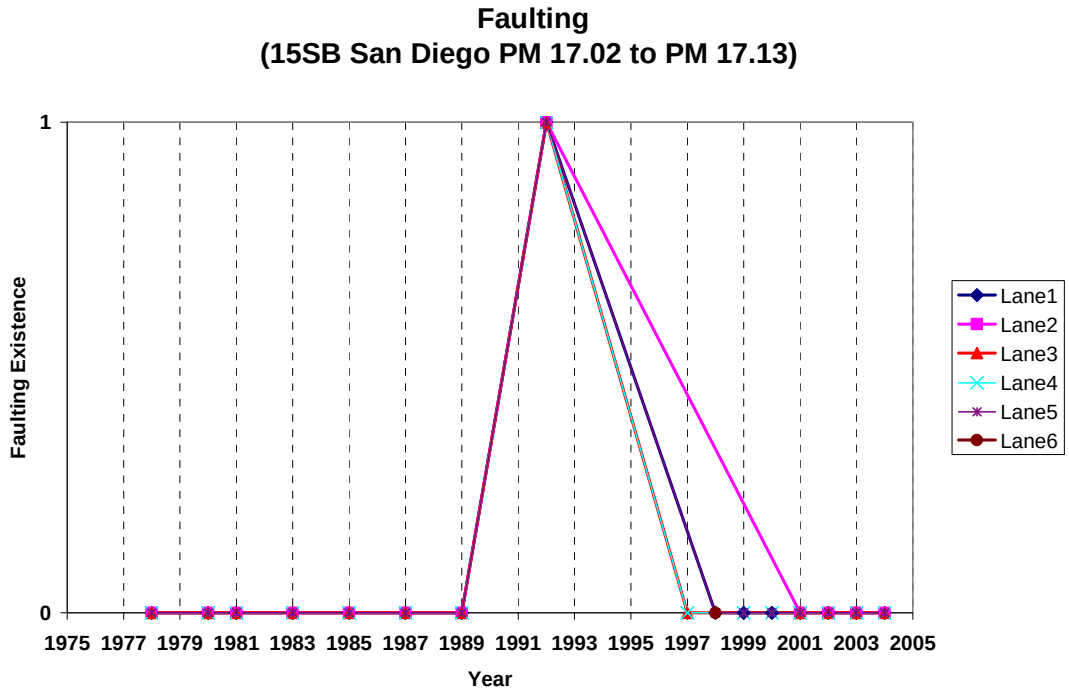

Figure 3.14: Faulting for I-15 SB, San Diego, PM 17.02 to PM 17.13.

3.5. Spalling

Spalling data were very sparsely populated in the PMS database. From 1978 to 1992, spalling mostly had null values and sometimes had the symbols "S," "M," or "N." The description for these symbols could not be found by UCPRC personnel. From 1992 to 1994 spalling was recorded as a binary record ("Yes" or "No"). Since spalling data would have problems similar to faulting data (as discussed in the previous section), they are excluded from the study.

3.6. Findings from Rigid Pavement Distress Data Extraction

The following findings are based on the results of the data extraction process for rigid pavements:

1. First-stage cracking, third-stage cracking, and corner cracking data showed quite reasonable trends for almost all the sections. However, certain questions about maintenance activities (slab replacements) need to be addressed before the data are used.
2. Faulting and spalling data from the PMS cannot be used to track their progression with time and so cannot be used for calibration of fault prediction models. This problem arose not because of any shortcoming of the algorithm but rather because of the nature of the faulting data collected.
3. There seems to be some problem with the cracking data in 1997 because it consistently shows zero cracking.

4. Data between 1992 and 1997 are often quite sparse and the reason for this is not known.
5. The algorithm was highly successful in extracting reasonable cracking data for all rigid pavements (100 percent success rate). Data extracted from all the rigid sections and the rigid portion of the composite sections (before the AC overlay) are of good quality and will be used to calibrate the MEPDG crack prediction model.

4. FLEXIBLE PAVEMENT DATABASES

Data were extracted for flexible pavement sections that had structural information either from the GPR study or from field sampling done as part of the Quiet Pavement Study. There were 78 sections studied as part of this PMS data extraction effort. The details of the GPR study are discussed in detail in the GPR report (10). The sites for which data are extracted are shown in Table 4.1.

The flexible distresses recorded in the PMS are Alligator A cracking (AAC), Alligator B cracking (ABC), rutting, and roughness. AAC and ABC are measured and recorded in feet for the surveys done between 1992 and 1997. For pre-1992 and post-1997 surveys, the data were in percentage of wheelpath cracked, and to have consistent units for AAC and ABC throughout the data between 1992 and 1997 were converted by UCPRC to percentage of wheelpath cracked. Rutting was converted to a binary variable (like faulting and spalling in rigid pavements). Rutting is not analyzed in this study for the same reasons that faulting and spalling were not analyzed.

4.1. Alligator A and Alligator B Cracking

Plotting the cracking percentages recorded in the PMS showed early cracking, subsequent increases as cracking progressed, and decreases that may have resulted from maintenance or rehabilitation activities.

Figures 4.1 through 4.5 show plots of AAC and ABC that exemplify the values and trends of data extracted for alligator cracking. Figures 4.1 and 4.2 show a site with reasonable crack initiation and progression data (both AAC and ABC). However, there are questions about some of the data points. For example, AAC for Lane 3 drops to nearly zero in 1985 and then jumps to 55 percent cracking in 1987. This trend is not seen in ABC for Lane 3 from 1985 to 1987. Both AAC and ABC for Lane 3 drop to zero percent in 1999, suggesting the possibility of maintenance or rehabilitation activities. Trends in AAC and ABC values are not as similar for Lane 2. Lane 2 drops to zero percent AAC in 2000 but ABC is 25 percent in the same year. If the algorithm is working effectively, then additional effort may be needed, such as searching for historical information about maintenance or rehabilitation, to identify the causes of these trends. Unfortunately, maintenance done by Caltrans forces is not recorded in the PMS, and the records for contract maintenance usually show only the boundaries of the project, not where the work was actually done within those boundaries. Implementation of remedies for solving this problem of identifying where contracted work is done, what is done, and when it is done within the total contract duration are in the Caltrans work plan for improving the PMS.

Table Table 4.1: Flexible Pavement Sections for Which PMS Data Were Extracted.

Dist.	County	Rte.	Direct.	Begin PM	End PM
3	ED	50	WB	17.30	18.30
3	ED	50	WB	18.50	20.30
3	SAC	16	EB	22.00	24.00
3	SAC	16	EB	2.50	20.70
3	SAC	50	EB	16.10	17.30
3	SAC	50	EB	14.30	15.76
3	SAC	50	EB	15.76	16.10
3	SAC	50	EB	16.10	17.01
3	SAC	50	EB	17.01	17.20
3	SAC	50	EB	17.20	18.70
3	SAC	50	EB	18.70	19.23
3	SAC	50	EB	19.23	21.50
3	SAC	50	EB	21.50	22.70
3	SAC	50	EB	22.70	23.14
3	SAC	99	SB	15.90	15.66
3	SAC	99	SB	15.66	15.16
3	SAC	99	SB	11.26	10.07
3	SAC	99	SB	10.07	9.26
3	SAC	99	SB	9.26	8.96
3	SAC	99	SB	8.96	8.46
3	SAC	99	SB	8.46	7.96
3	SAC	99	SB	7.96	7.36
3	SAC	99	SB	7.36	6.01
3	SAC	99	SB	6.01	4.39
3	SAC	99	SB	3.26	3.16
3	SAC	99	SB	3.16	2.70
3	SAC	99	SB	2.70	2.26
3	SAC	99	SB	2.26	2.16
3	SAC	99	SB	1.26	0.79
3	SAC	99	SB	0.79	0.33
3	SAC	99	SB	0.33	0.12
3	SAC	99	NB	32.67	33.36
3	SAC	99	NB	33.36	35.37
3	SAC	99	NB	35.37	36.86
3	SOL	505	SB	9.36	8.96
3	YOLO	45	SB	12.92	8.02
3	YOLO	45	SB	8.02	5.80
3	YOLO	45	SB	5.80	0.27

Dist.	County	Rte.	Direct.	Begin PM	End PM
4	ALA	92	EB	6.63	8.80
4	ALA	238	NB	12.60	14.30
4	MARIN	37	WB	12.10	14.40
4	MARIN	101	NB	18.90	23.10
4	MARIN	101	SB	2.50	8.50
4	MARIN	101	SB	0.00	2.50
4	MARIN	580	WB	2.50	4.80
4	NAPA	29	NB	12.20	14.50
4	NAPA	128	EB	5.10	7.40
4	SCI	237	EB	1.00	2.30
4	SCl	85	SB	1.90	4.70
4	SCl	237	EB	3.80	7.10
4	SOL	80	WB	44.72	42.67
4	SOL	80	WB	42.67	41.90
4	SOL	80	WB	41.90	40.30
4	SOL	80	WB	40.30	39.74
4	SOL	80	WB	9.70	8.30
4	SOL	80	WB	6.81	5.63
4	SOL	80	WB	5.63	5.30
4	SOL	80	WB	5.30	4.43
4	SOL	80	WB	4.43	3.49
4	SOL	80	WB	3.49	3.23
4	SOL	80	WB	3.23	2.88
4	SOL	80	WB	2.88	2.22
4	SOL	80	WB	2.22	1.78
4	SOL	80	WB	1.78	1.14
4	SOL	80	WB	1.14	0.00
4	SOL	113	NB	0.10	18.00
4	SON	1	NB	0.00	8.40
4	SON	37	WB	0.30	2.00
4	SON	121	EB	3.40	7.30
5	SCr	17	NB	6.00	12.60
5	SLO	46	WB	10.80	22.00
7	VEN	34	WB	4.30	6.30
8	SBD	58	WB	0.00	5.30
8	SBD	83	NB	6.40	9.50
8	SBD	395	NB	18.10	42.70
10	AMA	49	SB	14.70	17.60
10	CAL	4	WB	0.00	18.80
10	SJ	99	SB	19.00	21.80

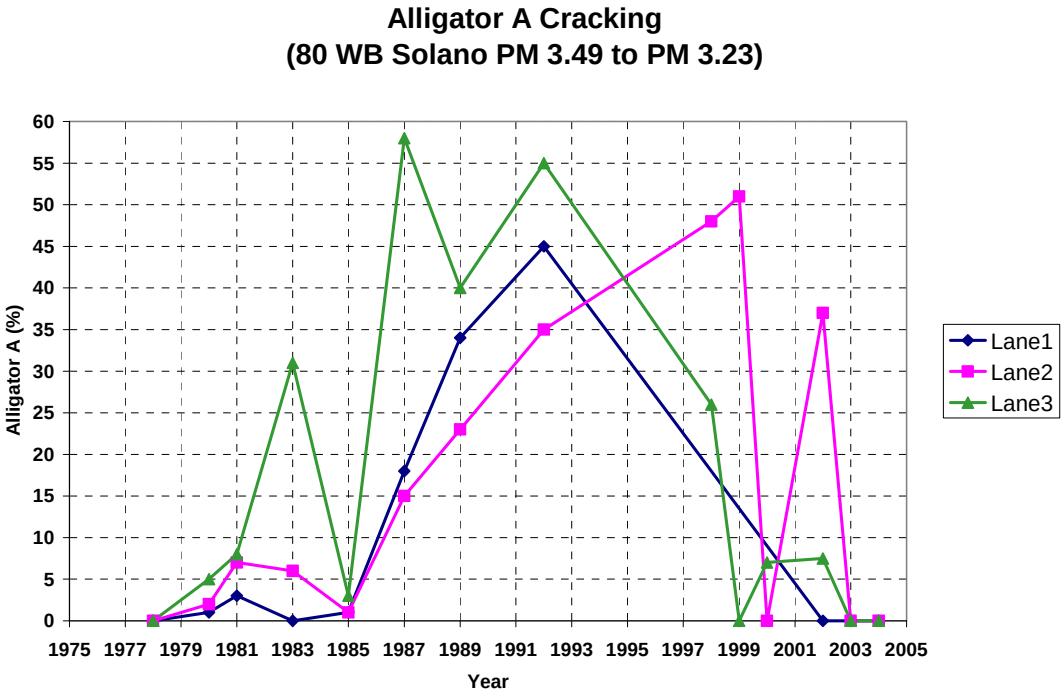

Figure 4.1: AAC for I-80 WB, Solano, PM 3.49 to PM 3.23.

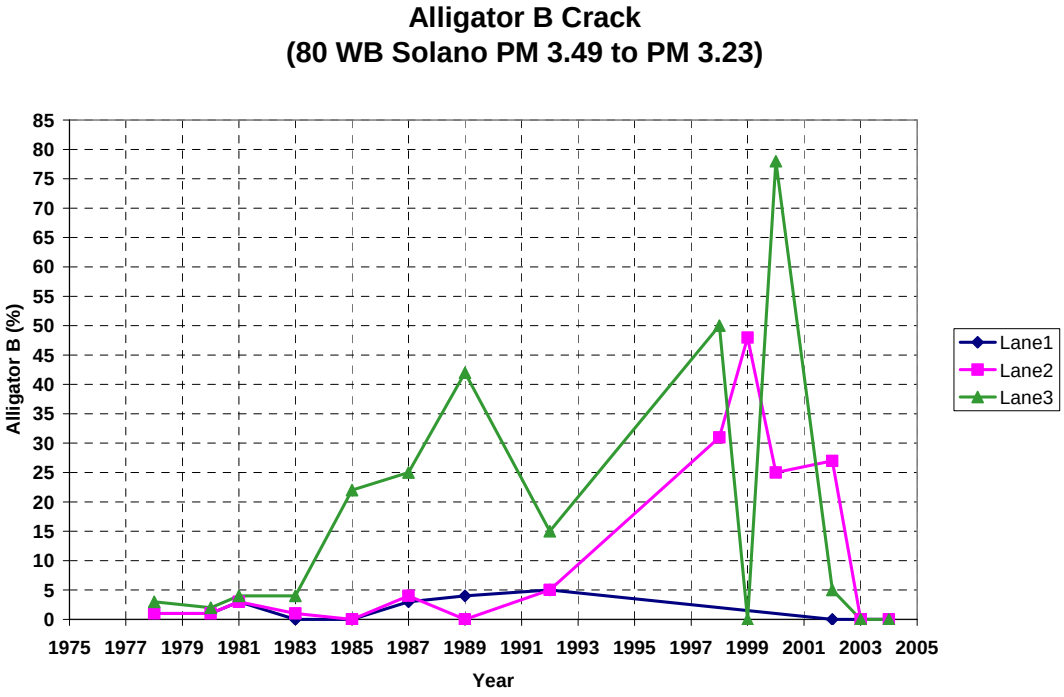

Figure 4.2: ABC for I-80 WB, Solano, PM 3.49 to PM 3.23.

Figure 4.3 shows AAC for a site on US 50. The plot shows a reasonable trend for cracking in Lane 2 up to 1989. After that year, cracking in the lane drops every year until AAC reaches zero percent in 1996. After rising in 1999 and 2000, cracking in the lane again drops to zero percent in 2002. Trends of AAC for the other lanes are unclear, suggesting the need for further effort to identify trends and their causes.

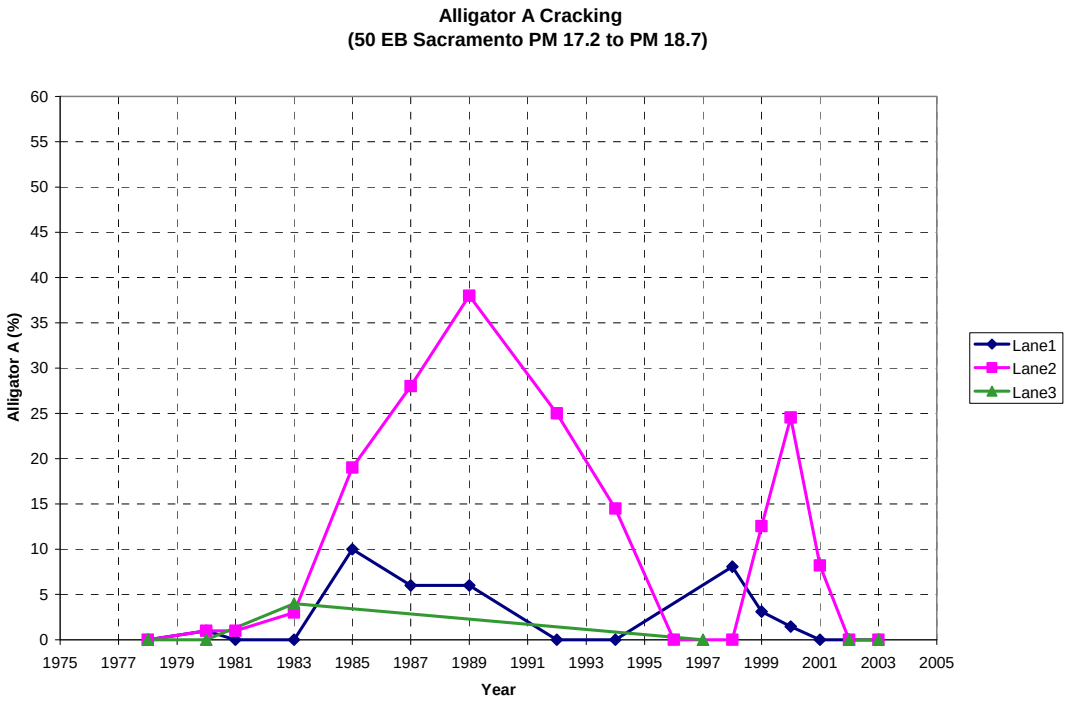

Figure 4.3: AAC for US 50 EB, Sacramento, PM 17.2 to PM 18.7.

Figures 4.4 and 4.5 show a site with data that do not show reasonable values and trends. There are too many ups and downs in the distresses, leading to the conclusion that looking into the history of maintenance activities is of little use for this site. These sections were strongly affected by dynamic segmentation, and possibly poor quality data were recorded or repeated maintenance was done that cannot be found in the contract history files.

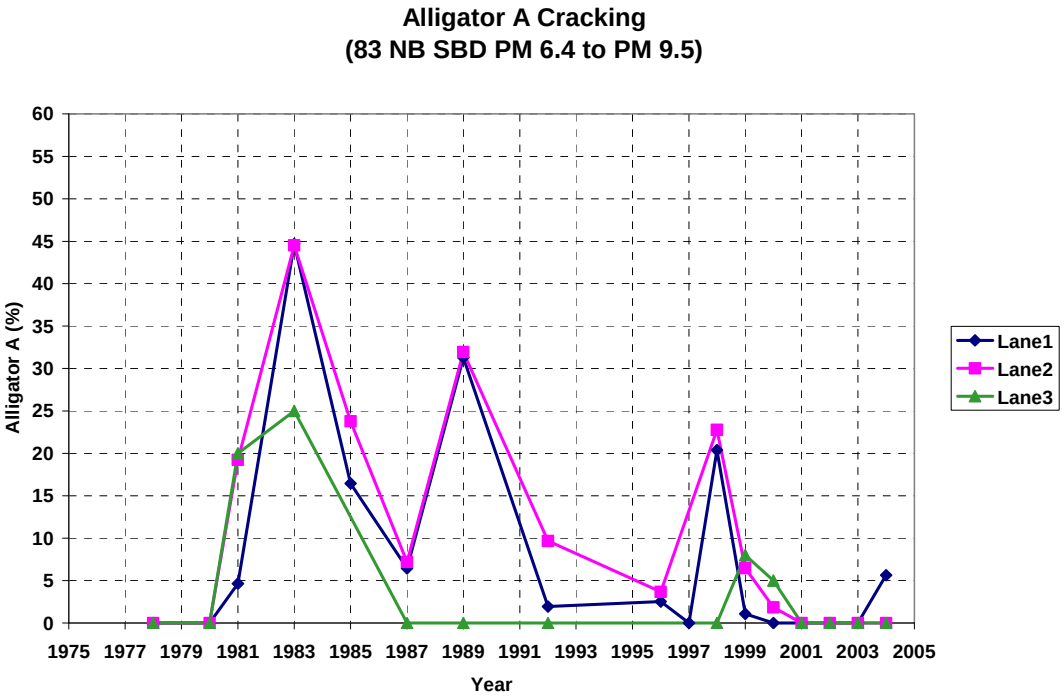

Figure 4.4: AAC for SR 83 NB, Sacramento, PM 6.4 to PM 18.7.

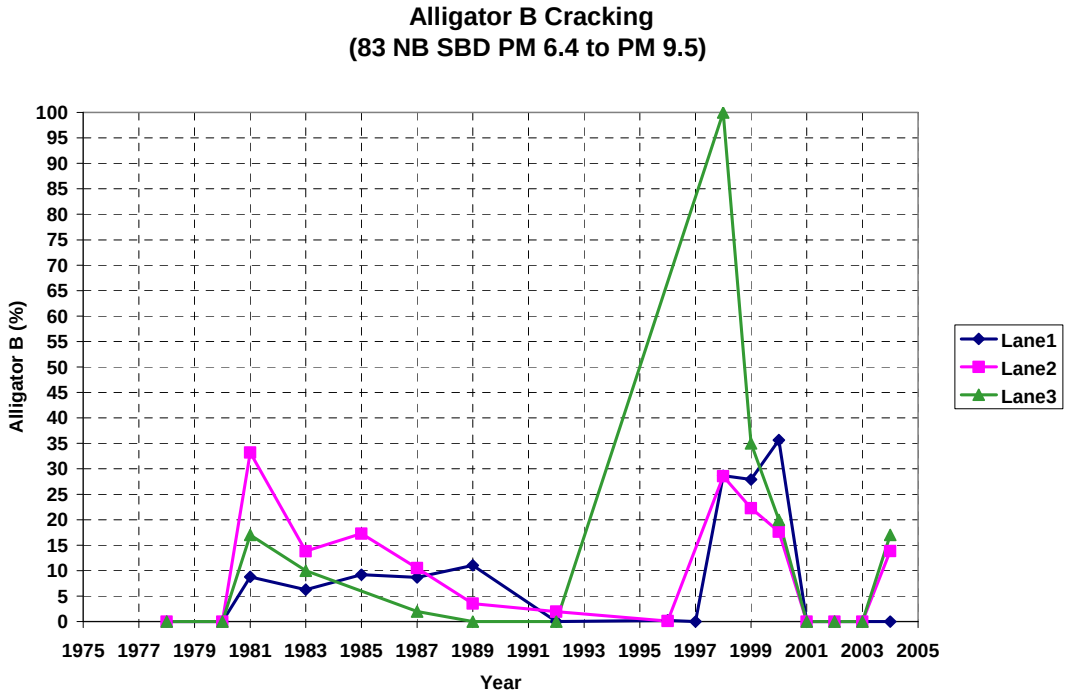

Figure 4.5: ABC for SR 83 NB, Sacramento, PM 6.4 to PM 9.5.

4.2. Findings from Flexible Pavement Distress Data Extraction

The following findings are based on the results of the data extraction process for flexible pavements:

1. There is a great deal more variability in the usefulness of the data extracted from the flexible pavement sites than there is in the data from the rigid pavement sites. This indicates that the problem of dynamic segmentation affected flexible pavements more than rigid pavements. This is most likely due to the facts that rigid pavement sections are surveyed over their entire length and the segment boundaries remain more constant, compared to the flexible pavement sections where only the first 100 ft of each segment are surveyed, and the dynamic segmentation process has resulted in more frequent changes in segment boundaries and lengths.
2. The data between 1992 and 1997 are very sparse.
3. Of the 78 flexible sections analyzed, 50 of them showed clear and useful trends of crack initiation and/or crack progression for at least part of the performance history. This indicates that the algorithm works reasonably well for flexible pavements. However, to use the performance history with crack initiation and progression models it is necessary to acquire details of the maintenance activities on the sections.

5. COMPOSITE PAVEMENTS

All composite pavement sections in this study had been rehabilitated using the Cracked and Seated Overlay (CSOL) method. The weighting algorithm was applied to PMS data and used to extract data for 53 sites. Field work to extract cores was performed for these sections. Distresses recorded for composite pavements in the PMS are first-stage cracking, third-stage cracking, corner cracking, faulting for the rigid pavements portion of the PMS time history prior to overlay; Alligator A cracking and Alligator B cracking for the period after the AC overlay; and roughness.

In CSOL pavements there is no fatigue cracking leading to alligator cracking as occurs in the wheelpaths of flexible pavements. Instead, cracks in the underlying layers are reflected upward, leading to reflective cracking. It is often hard to identify reflective cracking unless the underlying layer of the pavement section is known. Caltrans has no comprehensive database of pavement structure cross-sections, and the PCS crew has never had this information to determine whether they are surveying a flexible pavement or a composite pavement. Because of this difficulty, it is suspected that Alligator A and B cracking reported in the PMS was actually reflective cracking. Since longitudinal cracking near the wheelpaths occurs frequently on rigid pavements in California, its reflection up through the asphalt overlay would also occur in the wheelpaths, leading PCS surveyors to record it as Alligator cracking. Also, because it is reflective cracking of rigid pavement longitudinal cracks, the terms “Alligator A” and “Alligator B” do not have much meaning as used in the PCS. There is no reason to track them separately for composite pavements, even though it appears that way in the PCS database.

For this reason, an index called the “Reflective Cracking Index” (RCI) was developed to quantify reflective cracking. RCI is generated by summing up Alligator A and Alligator B cracking in terms of percentage of the wheelpath cracked. It is possible that transverse cracks and joints in the rigid pavement that are reflected may not have been recorded during the condition survey, as reflected transverse cracks do not resemble the pattern for alligator cracking and transverse cracking is not recorded for flexible pavements.

The composite pavement sections on which the weighting algorithm was applied in this study are listed in Table 5.1. Sections on a particular route are very close to each other, usually not more than a couple of miles apart.

Table 5.1: Composite Pavement Sections for Which PMS Data Were Extracted

Route	Direction	District	County	Number of Sections	Starting PM	Ending PM
5	NB	2	Shasta	9	29.17	39.9
5	SB	2	Shasta	5	28.9	31.7
101	N	5	Santa Barbara	23	21.18	83.9
58	W	6	Kern	6	70.89	75.87
580	E	10	San Joaquin	5	5.02	8.88
580	W	10	San Joaquin	5	5.35	8.70

5.1. Reflective Crack Index Data

The trends in cracking data for the rigid portion of CSOL sections (before the AC overlay) are similar to rigid pavement section distresses explained in previous sections of this technical memorandum. This section deals with the quality of data for Reflective Cracking Index.

Figure 5.1 shows the RCI for a section on I-5 Shasta and Figure 5.2, revealing the third-stage cracking for the same site before CSOL was done. It can be seen that in this case a high percentage of third-stage cracking was the reason for CSOL, which was done sometime between 1987 and 1989. The plots also show that in this section no reflective cracking is evident, even after 15 years of CSOL.

None of the sections on I-5 near Shasta showed any reflective cracking. At some sites CSOL was done even though there was not much cracking. It is likely that in such cases faulting triggered the CSOL rehabilitation, though this is not detectable from the historical PMS data.

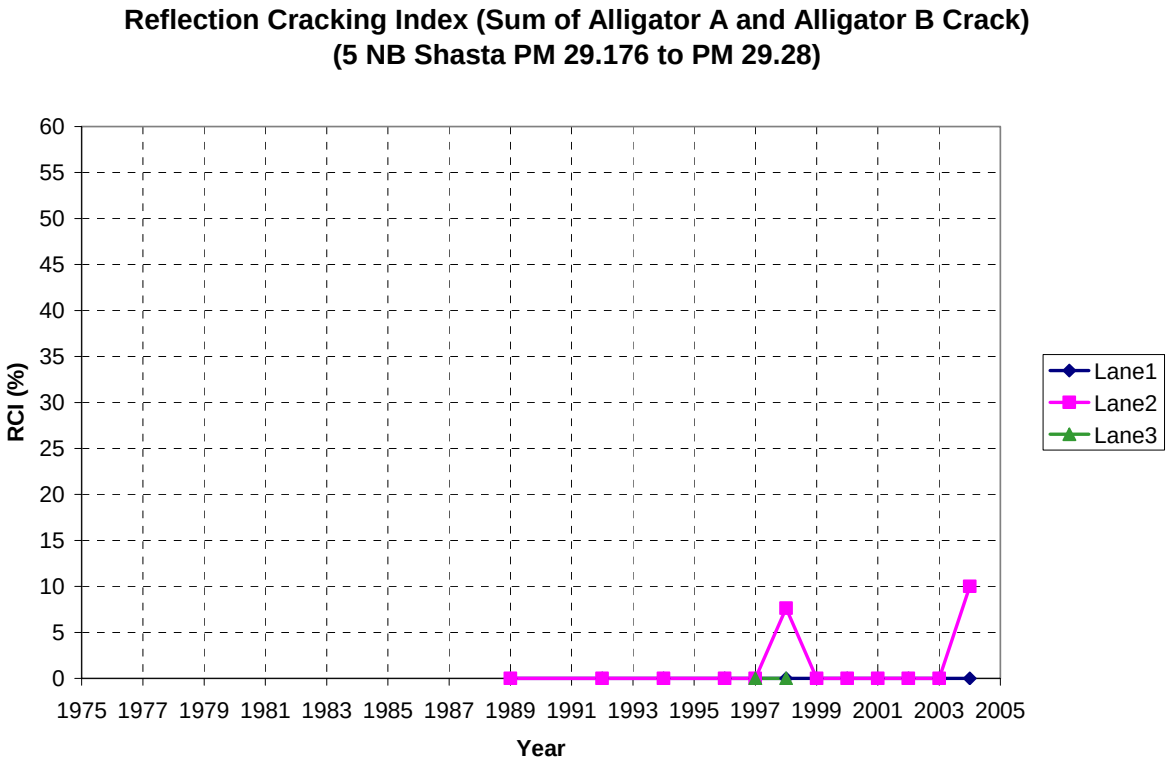

Figure 5.1: RCI for I-5 NB. Shasta, PM 29.176 to PM 29.28.

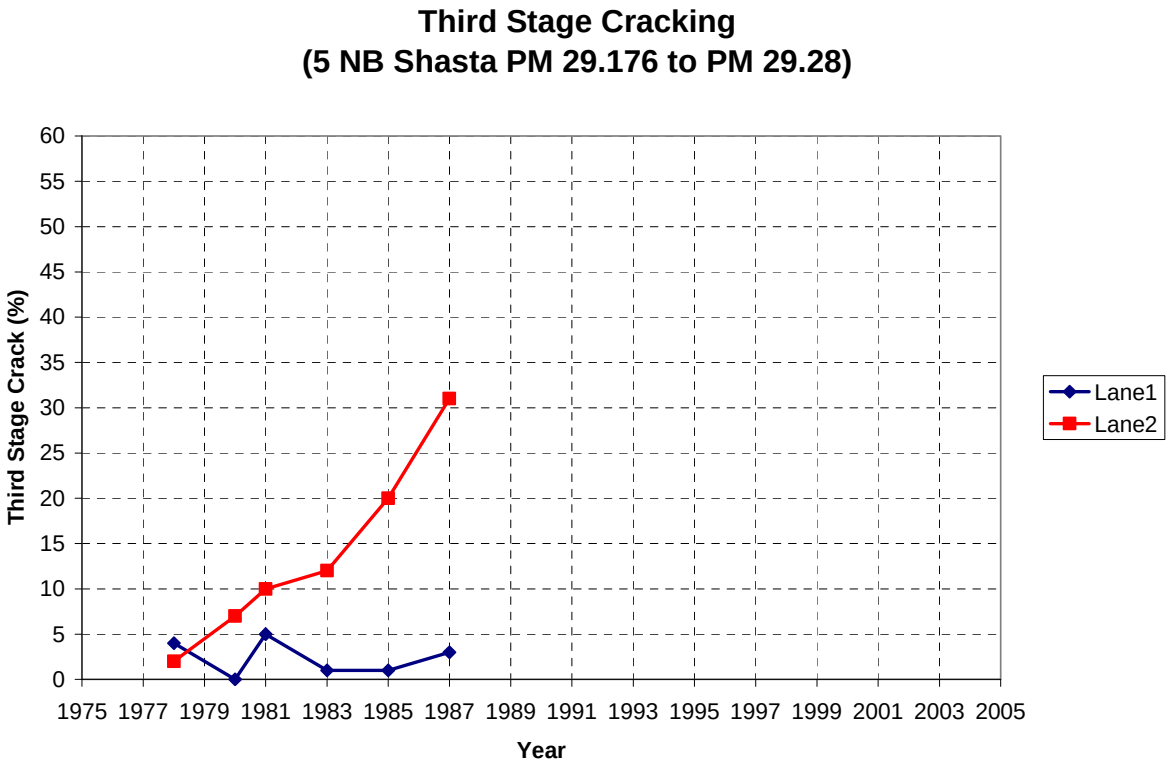

Figure 5.2: Third-stage cracking on I-5 for the site corresponding to Figure 5.1.

Figure 5.3 shows RCI for a site on US 101 NB. This site had about 40 percent third-stage cracking in 1992 (distress plot not shown here), which may have triggered the CSOL activity. Flexible pavement distresses were recorded starting in 1993, indicating that CSOL was done in 1992 or 1993. This site developed reflective cracking by 1999, less than seven years after CSOL rehabilitation. The reason for the drop in reflective cracking from 2000 to 2003 is unknown and for an explanation would require finding historical records other than those that could be located for this study. Not all the sites on US 101 showed reflective cracking. Some of them had no reflective cracking even by 2004, the final year of data in the PMS database.

Similar information can be gathered from PMS plots of sites on routes SR 58 and I-580. Plots indicate that SR 58 had CSOL sometime between 1996 and 1998 and that all sections but one developed no reflective cracking until 2004. Sections on I-580 that were studied had CSOL between 1992 and 1997, and none of them developed reflective cracking.

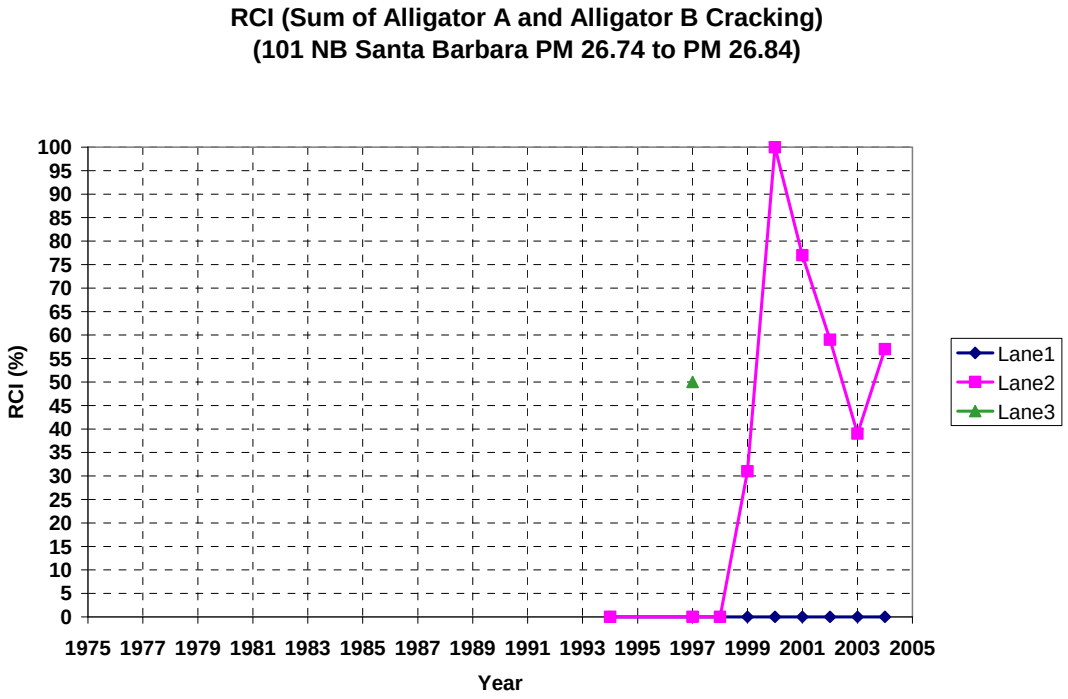

Figure 5.3: RCI for US 101 NB, Santa Barbara, PM 26.74 to PM 26.84.

5.2. Findings from Composite Pavement Distress Data Extraction

The following findings are based on the results of the data extraction process for composite pavements:

1. The PMS plots indicate the approximate year in which CSOL was constructed, which is important when the only construction date information is a multiyear contract showing beginning and end dates.
2. The minimum and maximum life of a CSOL before it develops reflective cracking was observed to be 5 and 15 years, respectively. It should be noted that this observation is based on a very limited number of sections analyzed as part of this study.
3. The data between 1992 and 1997 were very sparse.
4. Almost all the 56 sections analyzed yielded clear and useful trends for Reflective Cracking Index (RCI), which is the sum of Alligator cracking types A and B in terms of percentage of the wheelpath cracked. As is explained in this chapter, the PCS identifies this cracking as alligator cracking, though in fact it is mostly reflective cracking from longitudinal cracking in the underlying rigid pavement. However, these data need to be used in conjunction with better maintenance history information for validating any mechanistic-empirical reflective cracking models.

6. ROUGHNESS

6.1. Roughness Data

The weighting algorithm was used to extract roughness (sometimes also referred to as "ride quality" or "smoothness") data for all the sites discussed in Chapters 3, 4, and 5 of this memorandum. Roughness was recorded as Ride Score (RDS) collected using a Mays Meter in the databases from 1978 to 1992. From 1997 to 2004, roughness was recorded using the International Roughness Index (IRI) calculated from data collected with an inertial profiler. There are little or no roughness data between 1992 and 1997, as mentioned previously. Caltrans practice for collecting RDS and IRI is briefly summarized in Section 2.2 of this memorandum.

IRI is used in mechanistic-empirical models, including the MEPDG. Roughness recorded as RDS is not predicted by mechanistic models. For this study, both RDS and IRI were plotted on the same graph (indexed to separate vertical scales), both to look for reasonable trends (roughness increasing with increasing age between maintenance and rehabilitation treatments) and to see whether similar trends can be observed for the two parameters. Some example plots showing the roughness data extracted appear in Figures 6.1 through 6.6. RDS values are generally relatively constant in most of the plots, though differences between lanes are discernible. IRI measurements typically show more substantial differences between lanes and from one year to another.

Figure 6.1 shows roughness on I-80 between Vacaville and Fairfield. RDS values show little variation over the period in which it was collected. IRI data show a drop in IRI in 1999, suggesting that grinding was done on Lanes 2, 3, and 4 (this has been confirmed both by visual observation of the surface texture and by Caltrans staff familiar with the corridor). Roughness dropped in 2003 but increased the next year for nearly all lanes. This may indicate a problem (e.g., equipment malfunction or calibration error) in that year.

Figure 6.2 shows roughness data for SR 99 in southern Sacramento County. These data show an overall gradual increase in RDS. IRI values are relatively constant (except in 1999) in Lane 1 but decrease in Lane 2 and drop below 50 at a site on SR 99.

Figure 6.3, which shows data from I-15 in San Diego County, also reveals a decreasing trend and low IRI values. This plot also shows the drop in IRI values in 2003, as shown in Figure 6.1. Figure 6.4 shows data from SR 58 in Kern County, which has a trend of increasing IRI data. The dip in IRI during 2003 is again evident for Lane 1 roughness. Figure 6.5 shows an overall trend of increasing IRI in all lanes for a section

of US 101 in Marin County. RDS data are generally consistent except for Lane 5, where roughness varied substantially.

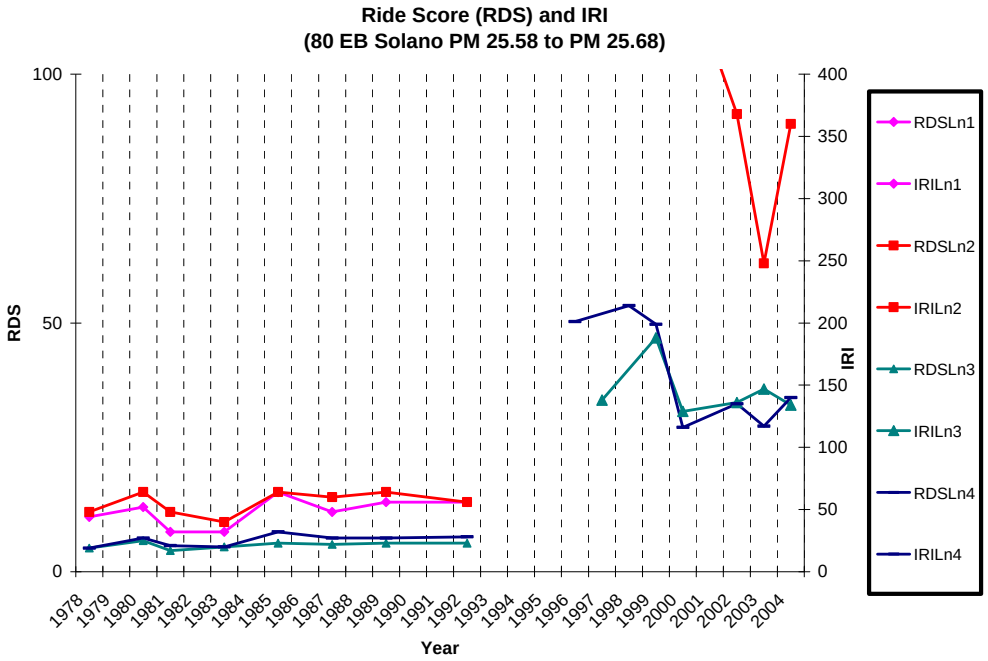

Figure 6.1: Ride Score (RDS) to 1993 and IRI from 1994 for I-80 EB, Solano, PM 25.58 to PM 25.68.

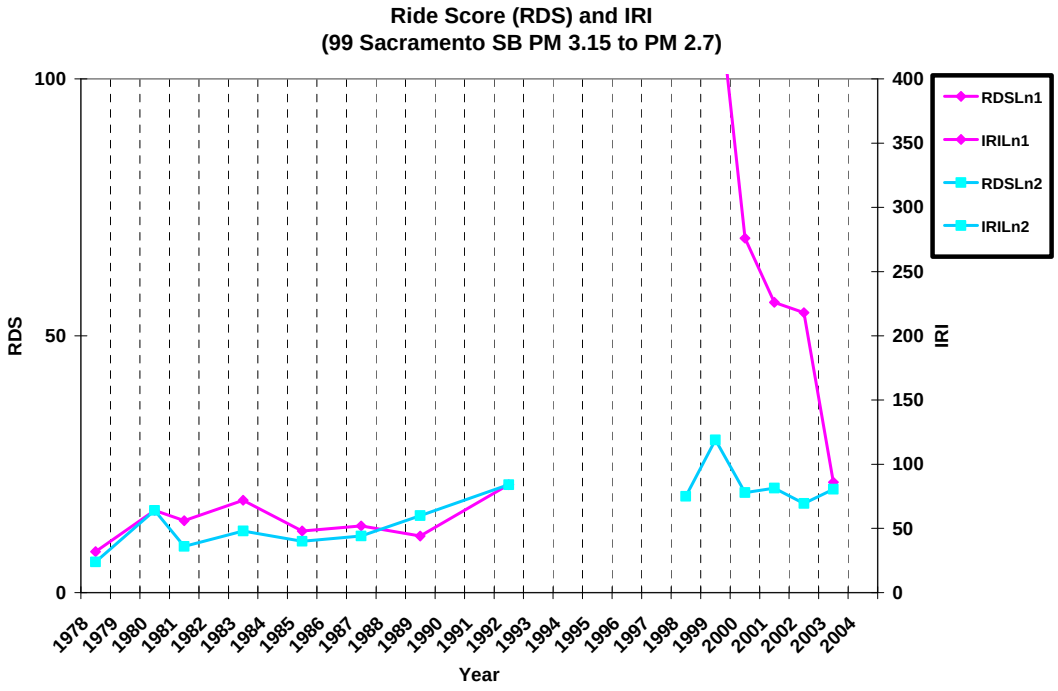

Figure 6.2: Ride Score (RDS) to 1993 and IRI from 1994 for SR 99 SB, Sacramento, PM 3.15 to PM 2.7.

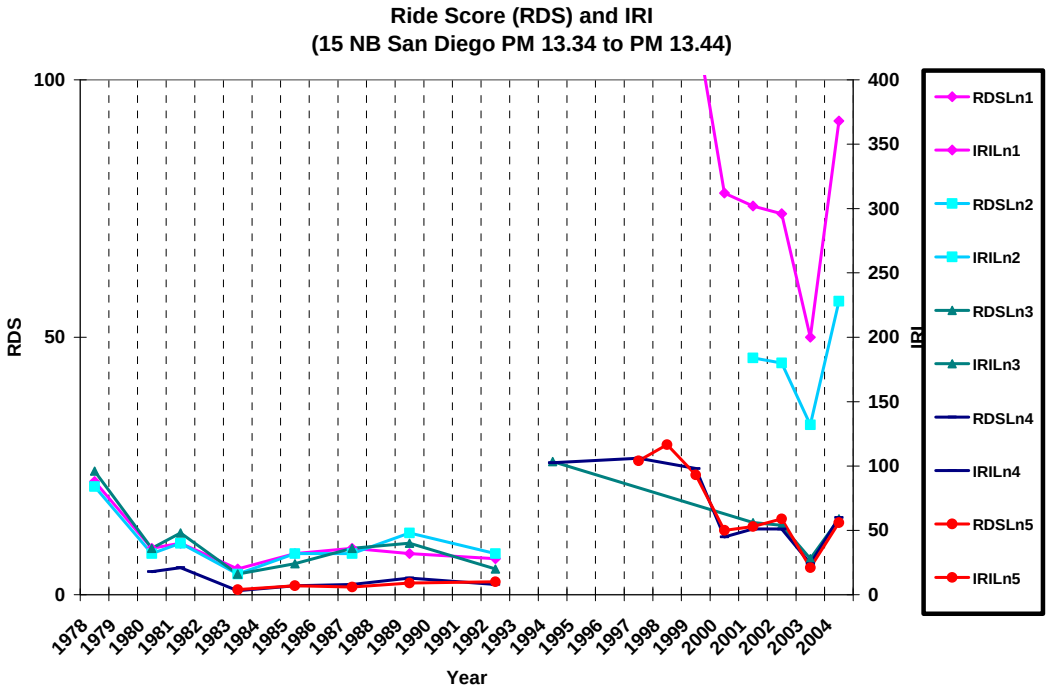

Figure 6.3: Ride Score (RDS) to 1993 and IRI from 1994 for I-15, San Diego, PM 13.34 to PM 13.44 site.

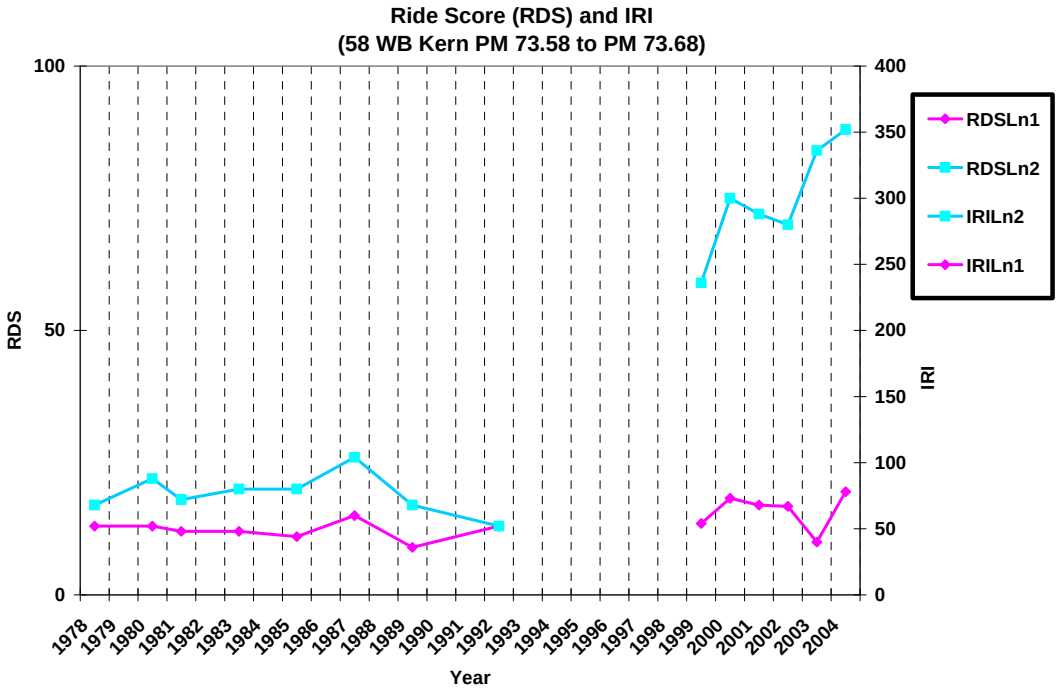

Figure 6.4: Ride Score (RDS) to 1993 and IRI from 1994 on SR 58 WB, Kern, PM 73.58 to PM 73.68.

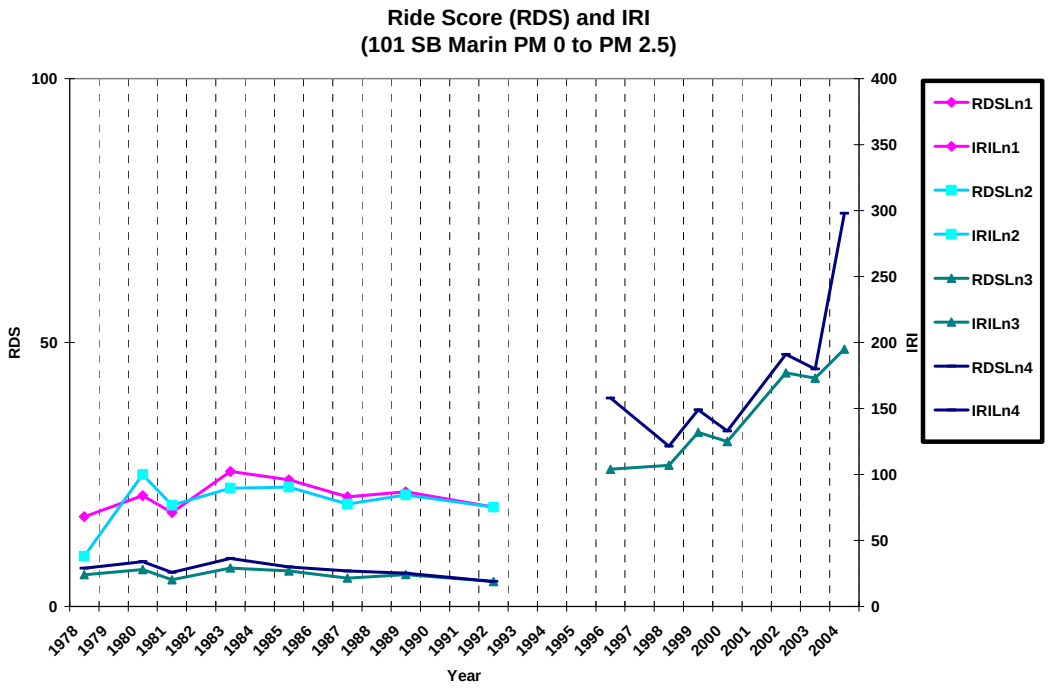

Figure 6.5: Ride Score (RDS) to 1993 and IRI from 1994 on US 101 SB, Marin, PM 0 to PM 2.5.

6.2. Findings from Roughness Data Extraction

The following findings are based on the results of the data extraction process for the roughness data:

1. Most of the sites had a drop in the IRI data in the year 2003, indicating that something might be wrong with the equipment that year.
2. There is no data or very little between 1992 and 1997. It is likely that little roughness data were collected during that period as the transition was made from Ride Score to IRI, which involved a change of equipment.
3. IRI in certain cases is unreasonably low, going below 30 inches per mile. It is difficult to build new pavements with IRI of less than that value and values this low would not be expected on pavements that have not had recent overlay.
4. IRI shows a decreasing trend in the majority of the cases when there was no recorded maintenance or rehabilitation project occurring. It is not certain whether this could be attributed to the algorithm or to the poor quality of the IRI data.
5. IRI data trends for individual projects cannot be used for calibration of mechanistic-empirical roughness models because the trends do not appear to be reasonable.

7. CONCLUSIONS AND RECOMMENDATIONS

Conclusions are presented for the two objectives of this study: (1) to develop a methodology that enables extraction of historical pavement condition data from the Caltrans PMS to overcome or partly mitigate the confounding effects of dynamic segmentation and (2) to apply the method and extract performance data.

7.1. Conclusions

7.1.1 Weighting Algorithm Methodology

7.1.1.1 Capabilities of the Algorithm

The algorithm developed enables weighting of the extent of the Caltrans Pavement Condition Survey (PCS) distress and ride quality data in the PMS database to attempt to calculate a consistent measure through time for a fixed segment of the state pavement network. This provides the possibility of creating performance time histories with respect to test sections or construction projects that have been documented in the past as well as segments of interest that may be identified in future research projects.

Pavement conditions documented in the historical PMS database can be proportioned based on the weighting algorithm over a given segment of interest. Although not evaluated as part of this study, the algorithm is adaptable to adjustments in section boundaries, so it may enable fine-tuning of pavement performance trends when new information becomes available about project maintenance and construction history.

The weighting algorithm method is a simple and straightforward approach and can be applied both to various types of pavement (rigid, flexible, and composite) and to pavement performance variables (cracking, roughness). However, the algorithm does not overcome all the problems of developing performance histories based on data from dynamic segments.

7.1.1.2 Obstacles for the Algorithm

Use of the algorithm is labor intensive. Applying it in the current study required about 600 person-hours. This excludes additional time that would be needed to resolve the many uncertainties and questions about levels and variations in pavement performance. Follow-up activities would include searching for additional historical project maintenance and construction data, contacting District staff, and/or working with HQ engineers. Evaluating performance goes beyond use of the algorithm and requires

knowledgeable, experienced engineers who would need to make subjective judgments to interpret and augment results. The algorithm can work well for project-level investigation but is unsuitable for network-level application, such as for attempting to evaluate historical PCS data from the entire network for use in a new PMS database.

There are several additional obstacles to using the algorithm to show pavement performance levels and trends:

- The algorithm cannot adjust for or discern effects from changes over time in performance variable definitions and collection methods.
- Field operations, including differences of accuracy, precision, and repeatability of condition raters on the field crew, are not addressed by the algorithm and could impede efforts to develop reasonable performance trends.
- The algorithm cannot compensate for equipment malfunctions and calibration.
- Procedures (both in the office and in the field) that have changed or have not been documented will not be addressed by the algorithm.
- The algorithm cannot resolve or overcome the use of "zero" either to quantify level of distress or to denote that no entry recorded. During the course of the data extraction exercise, in many instances it was observed that a "zero" value for a particular distress type in the PMS could mean one or both of two things:
  1. No data were recorded that year.
  2. No distress was present.

  Judgment must be applied before inferring anything about "zero" values in the PMS database.
- The lack of roughness data from 1992 to 1997 is likely owing to very little roughness data having been collected in this period.
- The algorithm cannot identify when maintenance or rehabilitation was performed, though trends can suggest when work was done to improve pavement condition.
- The algorithm cannot identify the cause of unreasonable trends.
- The algorithm cannot completely overcome the effects of dynamic segmentation (see results for flexible pavements—which had much more dynamic segmentation than rigid pavements, and which produced less reasonable performance trends [as presented in Section 4]).

7.1.2 Pavement Performance Data Extracted from Applying the Algorithm

7.1.2.1 Rigid Pavement

Cracking (first-stage, third-stage, and corner) values and trends are clear and useful for all 46 rigid pavement sections in this study. Data recorded in 1997 consistently show zero cracking that could indicate that either there was no cracking or no value was recorded during the field condition survey. There are indications of maintenance activities (e.g., slab replacement) that would require follow-up investigation to confirm.

Reasonable trends for cracking probably are related to less dynamic segmentation of rigid pavements that occurred before 1994, in contrast to the condition surveys performed after that year. The PMS contains very little distress data for rigid pavements from 1992 to 1997.

Faulting and spalling data in the PMS do not show discernible trends.

7.1.2.2 Flexible Pavement

Unlike with rigid pavement cracking data, there is much variability in the usefulness of the cracking data extracted from the sections on flexible pavements in this study. This suggests that the problem of dynamic segmentation affected flexible pavements more than rigid pavements. However, almost two thirds of the flexible pavement sections (50 of the 78 studied) showed clear and useful trends of crack initiation and progression for at least part of the performance history. The PMS contains little distress data for flexible pavements from 1992 to 1997.

Clearer and more consistent trends in pavement performance may be possible with further study. This would require additional searching of records, some of which may not exist anymore, as well as working with Caltrans HQ and/or Districts to determine detailed project construction and maintenance histories.

7.1.2.3 Composite Pavement

The values and trends for cracking in composite pavements are similar to those for rigid pavement sections, with nearly all 53 composite pavement sections showing clear and useful trends. Plots of PMS data indicate the approximate time period when each section was rehabilitated using the CSOL strategy. For the limited number of sections in this study, service life before reflective cracking was recorded ranged from a minimum of 5 years to a maximum of 15 years. The use of a Reflective Cracking Index (based on the sum of Alligator A plus Alligator B cracking) provided reasonable values and trends for cracking. The PMS contains very little distress data for composite pavements from 1992 to 1997.

7.1.2.4 Roughness

Roughness measurements using IRI (since 1994) show a substantial difference between lanes and over time. Roughness values as measured by Ride Score (before 1992) are relatively constant, though differences between lanes are evident. Trends in IRI and Ride Score differ substantially. Correlation between IRI and Ride Score was not evaluated in this study. The PMS contains very little roughness data from 1992 to 1997.

Trends in IRI data show decreasing values at a majority of sites, with no indication that maintenance or rehabilitation was performed on those sites. Some IRI values are unreasonably low (below 30 inches per mile in some cases; below 50 inches per mile on pavements that have not had an overlay). IRI at most sites dropped in 2003. This decrease at so many sites suggests something may have occurred operationally or with equipment (e.g., malfunction or calibration error).

7.2. Recommendations

A number of recommendations regarding changes to the PCS and PMS are outside the scope of this report, have been made elsewhere, and are already incorporated in the Caltrans work plan for improving the Caltrans PMS.

For analysis of pavement preservation benefits, it is recommended that the following flexible pavement data be extracted from the PMS using the weighting algorithm for sections with known maintenance and rehabilitation histories for at least several years after the construction:

- Alligator A cracking
- Alligator B cracking

For calibration of mechanistic-empirical pavement design models, it is recommended that the following flexible and rigid pavement data be extracted from the PMS using the weighting algorithm for sections with known construction dates and with maintenance and rehabilitation histories for at least several years after the construction, and with pavement cross-sections determined from field sampling and as-built records:

- Alligator A cracking for flexible pavements
- Alligator B cracking for flexible pavements
- Alligator A and B cracking for composite pavements

- First-stage cracking for rigid pavements; use of this data will require extraction of other information to try to determine whether first-stage cracking is longitudinal or transverse
- Third-stage cracking for rigid pavements
- Corner cracking for rigid pavements

It is recommended that the extraction from the historical PCS database of the following data not be pursued further, for reasons discussed in this technical memorandum:

- Rutting in flexible pavements and composite pavements
- Faulting of rigid pavements
- Ride quality for both flexible and rigid pavements

8. REFERENCES

1. University of California Pavement Research Center. "Performance Review of Pavement Preservation Treatments." Work plan for prepared for the California Department of Transportation Division of Research and Innovation, Office of Roadway Research and Division of Maintenance Office of Pavement Preservation. Berkeley and Davis. October 2006.
2. Federal Highway Administration. Pavement Management System, http://www.fhwa.dot.gov/cadiv/techapps/pms.htm. Accessed July 2006.
3. Finn, F. "Pavement Management Systems—Past, Present, and Future." Public Roads. 62:1. July/August 1998. www.tfhrc.gov/pubrds/julaug98/pavement.htm. Accessed in July 2006.
4. Bartell, C., and Kampe, K. 1978. "Development of the California Pavement Management System Volume I: System Description." Caltrans, Division of Maintenance. Final Report. FHWA-CA-HM-7139-78-03.
5. Lea, J., and Harvey, J. T. August 2002 (Revision December 2004). "Data Mining of the Caltrans Pavement Management System (PMS) Database." Draft report prepared for the California Department of Transportation. Pavement Research Center, Institute of Transportation Studies, University of California, Berkeley. UCPRC-RR-2002-04.
6. Boucher, F. 1978. "Development of the California Pavement Management System Volume II: Manual of Rating Instructions." Caltrans, Division of Maintenance. Final Report. FHWA-CA-HM-7139-78-04.
7. Personal conversations with Caltrans Pavement Condition Survey crew members and review of data entry screens.
8. Budras, J. "A Synopsis on the Current Equipment Used for Measuring Pavement Smoothness." August 2001. www.fhwa.dot.gov/pavement/smoothness/rough.cfm. Accessed March 2008.
9. Madanat, S., Nakat, Z., Farshidi, F., Sathaye, N., and Harvey, J. October 2005. "Development of Empirical-Mechanistic Pavement Performance Models Using Data from the Washington State PMS Database." UCPRC-RR-2005-05. Report prepared for the California Department of Transportation. UC Pavement Research Center, Berkeley and Davis, CA.
10. Kohler, E., Santero, N., and Harvey, J. "Pilot Project for Fixed Segmentation of the Pavement Network." UCPRC-RR-2005-11. Report prepared for the California Department of Transportation. University of California Pavement Research Center, Berkeley and Davis, CA. December 2005 (Revision February 2006).
11. Lee, C., W. Nokes, and J. Harvey. "Performance of Pavement Preservation Treatments (1988 to 2003)." Draft Technical Memorandum: UCPRC-TM-2007-05. University of California Pavement Research Center, Berkeley and Davis, CA. (In progress.)