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THE RIGID PAVEMENT DATABASE: OVERVIEW AND DATA COLLECTION PLAN

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16. Abstract

The rigid pavement (RP) database contains historical distress data obtained from more than 400 continuously reinforced concrete pavements (CRCP) and jointed concrete pavements (JCP) across the state of Texas. Data collection efforts began in 1974 and have been undertaken periodically up to the present. The database contents include such performance-related variables as punchouts, patches, spalling, ride score, crack spacing, and deflection basins, as well as such inventory variables as location, design thickness, coarse aggregate type, climate, soil characteristics, date of construction, and overlay status. Taken as a whole, the RP database comprises a unique asset for empirical investigation of factors affecting long-term pavement performance in Texas.

In order to keep the RP database current and statistically representative of Texas' pavements, periodic reassessments of the database must be made in order to obtain updated sampling plans and new recommendations for future data collection. This report documents a study of the twenty-four-year database, examines the past and current demographics of the data, and identifies the need for improvement in critical areas. A plan is presented for the upcoming data collection in 1996, targeting thicker pavements, overlaid pavements, pavements constructed from new designs, and recently placed pavements. Additional needed inventory items, such as dates for recent overlays, more detailed climatic data, and improved location information, are also identified, with plans outlined for obtaining them. An entire chapter discusses the need for more precise location of the sections, as well as the suitability of available global positioning satellite (GPS) receiver technology for solving this ongoing problem.

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by

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and

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Research Report Number 2952-1

Research Project 7-2952

Expanding and Updating the Rigid Pavement Database

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

by the

CENTER FOR TRANSPORTATION RESEARCH

Bureau of Engineering Research

THE UNIVERSITY OF TEXAS AT AUSTIN

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PREFACE

This report describes the continuing development of the rigid pavement (RP) database, a twenty-four-year history of pavement conditions across Texas. Data and findings from this project (and others supporting the RP database) have been used by numerous other studies since the inception of the database in 1974. Chapter 1 of this report describes past and present implementation efforts in detail. It is expected that the RP database will continue to be of great value to the Texas Department of Transportation (TxDOT) through interaction with other projects and through indirect implementation of findings in this manner.

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Research performed in cooperation with the Texas Department of Transportation.

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CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

This report examines the current purpose, structure, and content of the rigid pavement (RP) database, a twenty-four-year history of the pavement conditions of continuously reinforced concrete pavements (CRCP) and jointed concrete pavements (JCP) across the state of Texas. The objective of this study is to examine the existing database and to give recommendations for improving it, so as to keep it relevant and useful as a research design and analysis tool for the foreseeable future.

1.2. OBJECTIVES OF THE RIGID PAVEMENT DATABASE

Since 1974, the first year of data collection, the organization and content of the database have changed many times, though the purpose of the database has remained the same: to provide a vital research tool for monitoring the historical performance of various rigid pavement designs over time under various traffic loadings and environmental conditions. Although some conditions can be simulated in the laboratory and, recently, even through accelerated on-site testing using innovative concepts such as the Texas Mobile Load Simulator (MLS), performance in the field, over time, is still the definitive measure. Even performance models that are developed mechanistically must be calibrated empirically using data from such sources as the RP database.

1.2.1. Network Management vs. Research

Performance models for design and management — and hence the data used to derive these models — fall into three broad categories of utilization: network management, project design, and research. Because network-level management addresses the needs of the entire pavement network, the percentage of the pavement population used for its associated data collection must be greater than that required of research-level work. And as an economic necessity, visiting more pavement sections requires collecting fewer, less-detailed data items, usually in some automated fashion that may represent a compromise between speed and accuracy. Approximate data of this sort are adequate for predicting the behavior of the network as a whole and for determining the efficacy of various rehabilitation options.

Because only a few data items can be collected, they must be selected carefully in a compromise between significance of effect and effort/expense required in their collection. In fact, it is one function of a research database to help identify which variables to collect at the network management level. As explained in Chapter 2, the RP database originally doubled as a network management database, but has become (since 1987) strictly a research database.

While research data collection requires visiting fewer sections, such data collection also requires more detailed data on each section. In order to ensure that the few sections visited adequately represent the entire network and the entire range of the variables collected, a balanced sampling plan or factorial is developed statistically. In this way, differences in performance between similar sections that are unimportant or unpredictable at the network level can hopefully be explained and predicted by the additional information collected. From year to year, some data items are dropped as they prove to be insignificant, while others are added for testing. A basic core of information is always collected to maintain continuity across the survey years. Eventually, variables proven to have significant effect on performance may be included in the network collection efforts if it is cost effective to do so.

1.2.2. Relationship with TxDOT PMIS

The TxDOT Pavement Management Information System (PMIS) is the Texas network-level database used for pavement management. The PMIS originated as an adoption and expansion of the initial network database, the Pavement Evaluation System (PES) developed at the Texas Transportation Institute in the early eighties (Ref 1). Federal mandate (the Intermodal Surface Transportation Efficiency Act of 1991, dubbed "ISTEA") prompted TxDOT to develop an automated statewide pavement management information system (hence PMIS) using as its core the updated PES database.

At the time of this writing, the PMIS performs a stratified sampling of pavements based on functional type: Interstate highways are sampled every year, U.S. and state highways are sampled every other year, and FM and RM roads are sampled every four years. A large number of data items are collected, but still fewer than would be collected by a project-level or research survey.

The RP database, as a network-level or pavement-management tool, has been supplanted by the PMIS, allowing the RP database to focus on research and project-level variables, which was its original primary intent. Now, the RP database complements the PMIS database, analyzing a greater number of variables and distresses and recommending to the PMIS those items to collect at the network level.

1.2.3. Relationship with SHRP

The Strategic Highway Research Program (SHRP) has, as its purpose, the development of pavement performance models for the entire country through a scale of effort not seen since the AASHO/AASHTO studies in the sixties. Unlike the AASHO road test that used a controlled experiment in a single location, SHRP has chosen sections across the nation to be studied in place by condition surveys and through destructive and nondestructive testing (NDT). In 1988, SHRP requested a copy of the RP database and used it to select several rigid pavement sections for monitoring in Texas.

Like the RP database, the SHRP database collection is based on a statistically designed sampling factorial that ensures adequate representation of all types of pavements, loadings, and climatic conditions across the inference space, which, in the case of SHRP, is the entire United States. The data items collected, sample size, and sampling rate for the SHRP rigid sections, therefore, differ from the RP database.

1.2.4. Calibration and Design of Analysis Models

One of the primary reasons for maintaining the RP database is to aid in the development of empirical performance models and to calibrate mechanistically derived models. These models are needed both at the network level and at the project or design level.

At the network level, the RP database was used in 1993 to develop distress prediction models for the TxDOT PMIS (Ref 2). Using the historical condition survey data in the database, simple models were constructed relating punchouts, patching, spalling, crack spacing, and serviceability loss to pavement age. Recommendations from Project 7-1908 served, in turn, to identify additional needs from the database that were incorporated into the next data collection effort. A current study, TxDOT Project 0-1727, is now underway to improve the models using the updated RP database, and to develop a better framework for incorporating them into a comprehensive pavement management system.

An example of how the database serves at the project or design level can be seen in the CRCP8 analysis and in CRCPAV design programs (Ref 3). CRCP8 predicts the performance (in terms of crack spacing, crack opening, steel stress, and rate of failure development) for a CRCP for any given design. CRCPAV reverses the process and finds steel reinforcement designs that will provide a user-specified level of performance. Both programs use a model derived from the RP database that predicts the rate of failure per accumulated 80-kN (18-kip) equivalent single axle load (ESAL). This model correlates early-age crack spacing (predicted by a mechanistic model) to probability of punchout through an empirical calibration dependent on portland cement concrete (PCC) flexural strength, coarse aggregate type, soil swelling, and level of reliability. The traffic, distress, and inventory data used to develop the calibration were taken from the RP database (Ref 4).

1.2.5. Interaction with QC/QA Effort

Currently, many state DOTs are switching from method-based to performance-based construction specifications. In the past, method specifications, wherein the contractor is told exactly how to construct the pavement, have been used almost exclusively; now, the focus is shifting to performance specifications, in which the contractor has a great deal more flexibility in construction (provided that certain performance goals are met). The difficulty then becomes how to predict performance twenty to thirty years in the future from measurements that can be made during or within a short time after construction.

One emerging approach to this problem is to compare concrete strength as built with the target design strength, and then to prorate estimated life and contractor payment accordingly. In order for this procedure to be effective, the designer must have a good idea of the relationship between initial PCC strength and pavement life.

An attempt to determine these values is currently underway as part of TxDOT IAC 98-0049, which is a QC/QA-related contract looking at rigid pavements. Using the RP database, a sampling factorial was constructed to include CRC pavements performing well and pavements performing poorly across the state. Care was taken to separate pavements constructed with limestone (LS) aggregate from those constructed with siliceous river gravel (SRG) aggregate, as these two materials have been determined by several studies to exhibit significantly different performance. Performance was measured in two ways: time from construction to first overlay (for older pavements), and initial (early-age) crack spacing and randomness for newer pavements. The resulting factorial is shown in Figure 1.1.

Using the above sampling factorial, the project team will visit and take six to ten core samples for strength testing from two to three paving projects in each group delineated in the factorial. In this way, typical tensile strengths can be determined for “good” and “poor” performing pavements, leading to recommendations for emerging performance-based specifications.

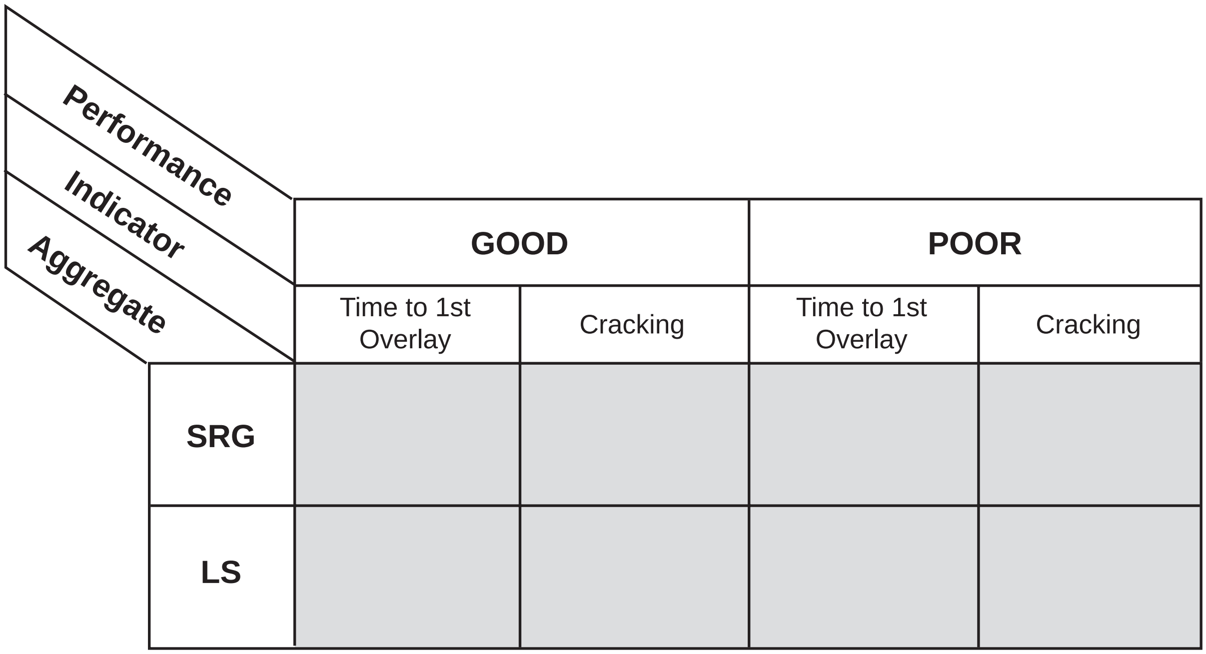

Figure 1.1 Experimental factorial for investigating the relationship of PCC tensile strength to pavement performance/life

1.2.6. Interaction with Past and Current TxDOT Studies

As can be seen from the examples given above, the RP database has contributed data to a number of past TxDOT research projects and is currently being used by several studies at any given time. Table 1.1 lists some of the past and present projects benefiting from the RP database.

Table 1.1 Selected research studies using the RP database

STUDY	STATUS	NATURE OF CONTRIBUTION
1244	Complete	Empirical Calibration of Mechanistic Model for Failure Rate
1908	Complete	Development of Initial Empirical Performance Models for PMIS
1727	Ongoing	Improvement of Performance Models for TxDOT PMIS
1739	Ongoing	Development of Framework for Life-Cycle Cost Procedure
1724	Complete	Investigation of Significant Factors for QC/QA
3925	Complete	Benchmark for Evaluating New CRCP Design Using SRG
SHRP	Ongoing	Selection of SHRP LTPP Sections in Texas
1169	Complete	Calibration of Fatigue Life Model for CRC Pavements
459	Complete	Validation of Subbase Friction Model to Predict Cracking
QC/QA	Ongoing	Establishing Key Performance Factors for Specifications
920	Complete	Pavement Remaining Life Estimation Prior to BCO

1.3. DESIGN PHILOSOPHY

1.3.1. Sampling Frequency

Focusing on research required a revision of the database design philosophy. The transition from network level to project level in 1987 entailed a reduction in the number of pavement sections visited from 100% of the state's RP inventory to just 328 paving projects in 14 districts; average section length was about 6.44 km (4 miles). Reducing the number of sections surveyed allowed more data items to be collected with greater precision, since it was now possible for the survey crews to collect data on foot instead of from a moving vehicle.

1.3.2. Sampling Variables

The ability to collect more variables, including some items that cannot be measured from a moving vehicle (such as crack width), allows the database sufficient flexibility to respond to current and anticipated research needs. Data items can be added to test their effect on performance, or omitted from later surveys as they are proven insignificant or no longer needed. For example, prior to the 1987 survey it was theorized that the cut/fill position might have an effect on pavement performance. Subsequent analysis has shown that theory to be correct, with the greatest (negative) effect on performance exhibited by sections placed on the transition between a cut and a fill. In another example, to support the TxDOT PMIS effort several asphalt distresses were added to the survey form to monitor the performance of overlaid rigid pavements. Because of all these changes, and to take advantage of advances in computer technology since 1974, the RP database was completely redesigned after the 1987 survey and continues to be modified as needed to support changes in the data items. One especially significant recent modification concerns a changeover from a paint marking system to one that uses a Global Positioning System (GPS) for much more reliable section location, as discussed in Chapter 4 of this report. Complete information on the transition to a research database is covered elsewhere (Ref 5), as are the most recent developments, among them the expansion to include jointed pavements (Ref 6).

1.3.3. Hierarchical Database Design

Organizationally, the database is set up in a hierarchical fashion. Each of the 328 paving projects has from one to six 304.8-m (1,000-ft) designated survey sections. Each survey section, in turn, has zero (never surveyed) to eight (surveyed every year a survey took place) records detailing the observed number of punchouts, patches, etc. Since the inventory or master file data (containing such items as location, construction date, etc.) never change, only one copy is stored; these data are linked to all of the corresponding survey records via key fields, as shown in Figure 1.2. A complete description of the database design and content can be found in CTR report 1342-3F (Ref 6).

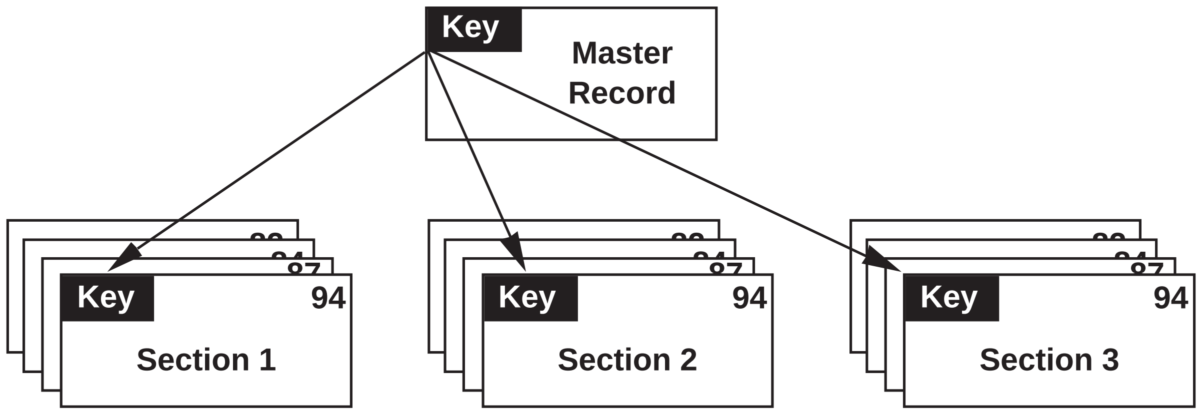

Figure 1.2 Conceptual structure of the RP database

1.3.4. Statistical Analysis System (SAS) Language Implementation

The database has been implemented in the SAS computer language since the 1987 redesign. SAS was chosen because it is a widely available language on both mainframes (IBM, VAX, UNIX) and microcomputers (IBM PC, Macintosh, and their compatibles). Also, SAS includes not only a wide range of data manipulation capabilities, but also an extensive set of data analysis tools, including ANOVA, regression, descriptive statistics, forecasting, spectral analysis, discriminant analysis, and much more. A working subset of SAS can be quickly learned by engineers or researchers. Finally, SAS can easily export and import files from such popular microcomputer applications as Microsoft Excel, Word, and Access for additional ease of analysis, report writing, and database storage, respectively.

1.4. OBJECTIVE OF THE REPORT

To keep the RP database current and statistically representative of Texas' pavements, periodic reassessments of the database must be made in order to provide updated sampling plans and new recommendations for future data collection. This report documents a study of the twenty-four-year database, examines the past and current demographics of the data, and identifies the need for improvement in critical areas. A plan is presented for the upcoming 1996 data collection effort, one that will target thicker pavements, overlaid pavements, pavements constructed from new designs, and recently placed pavements. Additional needed inventory items, such as dates for recent overlays, more detailed climatic data, and improved location information, are also identified, with plans outlined for obtaining them. An entire chapter discusses the need for more precise location of the sections, as well as the suitability of available GPS receiver technology for solving this ongoing problem.

1.5. ORGANIZATION OF THE REPORT

Chapter 1 introduced the objectives and design philosophy of the database. It has provided an overview of the RP database for those unfamiliar with it, and a summary for anyone who has used it in its present or a previous form.

Chapter 2 shows the evolution of the database from its inception in 1974 to its current design and content, prior to the beginning of the 1996 condition survey undertaken under Project 7-2952. This history includes some summarized material excerpted from reports on prior TxDOT studies 21, 177, 249, 388, 472, and 1342 (spanning the years 1974-1994), with references provided for those needing more detailed information. This material is reproduced and summarized here for the purpose of creating a document that brings together for the first time in one place all of the published information on the RP database. It is important to consider changes in the sampling size, data collected, and data collection procedures used in each survey year in order to understand the database and to use it to the best advantage.

Chapter 3 presents an analysis of the current demographics of the database, identifying trends and potential problems with the sampling methods and population characteristics that must be addressed to ensure that the database remains useful as a research tool well into the future. Specifically, a data collection plan is outlined to reduce the dominance of older, overlaid 20.3-cm (8-in.) CRC pavements in the sample pool by refocusing data collection efforts on newer, thicker CRCP and JCP sections with characteristics representative of current design standards. In addition, recommendations for collection of overlay dates, traffic, and environmental data are given, since these “inventory” items have not been updated since 1987. Finally, an updated form for condition surveys of asphalt-overlaid CRCP and JCP sections is suggested to provide data needed to develop performance models for these pavements by the ongoing TxDOT PMIS effort.

Chapter 4 addresses an issue that has been problematic for the RP database since the first data collection in 1974, namely, that of identifying and/or marking each section so that it can be revisited in subsequent years with sufficient precision and ease to facilitate an accurate historical record of distress trends. Procedures used in previous years are listed, and preliminary results obtained by testing two GPS receiver models (with and without differential correction) are compared theoretically and by field testing, resulting in a recommendation for a permanent and reliable system for locating survey sections.

Finally, Chapter 5 summarizes the report and makes recommendations for the 1996-1997 field survey.

CHAPTER 2. DATABASE HISTORY

2.1. INTRODUCTION AND OVERVIEW

At present, the rigid pavement database consists of two major parts: (1) the continuously reinforced concrete pavement (CRCP) database, which contains data collected from 1974 to the present on CRCP across the state, and (2) the jointed concrete pavement (JCP) database, which includes historical data from 1982, 1984, and 1994. Each database includes a number of related files arranged in a hierarchical database structure using the Statistical Analysis System (SAS) computer language (Ref 7); together, they are referred to in this document and elsewhere as the rigid pavement (RP) database.

2.1.1. The CRCP Database

The present configuration of the CRCP database is the result of a redesign undertaken in 1987 (Ref 5), which updated the 1974 design to take advantage of modern software tools. The 1996 CRCP database design is identical to the 1987 design; more data types are included but file structure and data access are the same. The JCP database was redesigned in 1993 under project 0-1342 as part of a major effort to coordinate with the performance modeling needed for the Texas PMIS. A thorough description of the content and how to access the CRCP database is given in CTR report 1342-3F (Ref 6), while a complete overview of the JCP database can be found in CTR report 1342-2 (Ref 8). Much of the information from these two reports is reproduced here for the convenience of the reader.

The CRCP database has evolved significantly since data were first collected for it in 1974. Data were collected in 1974, 1978, 1980, 1982, 1987, 1994, and, most recently, in 1996. Prior to each survey effort, a review of the previously collected data and analysis results using the data was made to determine the best data to collect and the best way to collect them.

Initially, data were collected for every CRCP section in the state, usually by breaking up the survey into 304.8-m (1,000-ft) sections. In 1984, the section lengths were doubled to 609.6 m (2,000 ft), to correspond with the state PMS system at the time. Finally, in 1987 a decision was made to collect only a representative sample of the CRCP inventory; for this, section lengths reverted to 304.8-m (1,000-ft) sections, though the sampling included far fewer sections than were sampled in previous years. A sampling scheme was developed that selected one to six sections per paving project, depending on a number of factors (e.g., project length, cut/fill position, and curvature; see Ref 9). The 1993-1994 and 1996-1997 surveys returned to the sections that were defined in 1987.

Figure 2.1 illustrates the changes in data sampling for a typical paving project, identified in the database as CFTR section 1001. Between 1974 and 1978, the Dallas-Fort Worth Toll Road was incorporated into the Texas highway system. Thus, IH-30 was extended 85 km (53 miles) by terminating in Fort Worth rather than in Dallas, resulting in the change in mileposts. Distressed areas were overlaid with ACP in the years shown. In 1987, six test sections were selected from the westbound lanes, and a detailed condition and deflection survey was performed. The process was repeated for the 1994 survey, and again in 1996. Thus, twenty-two years of performance data are available for these sections.

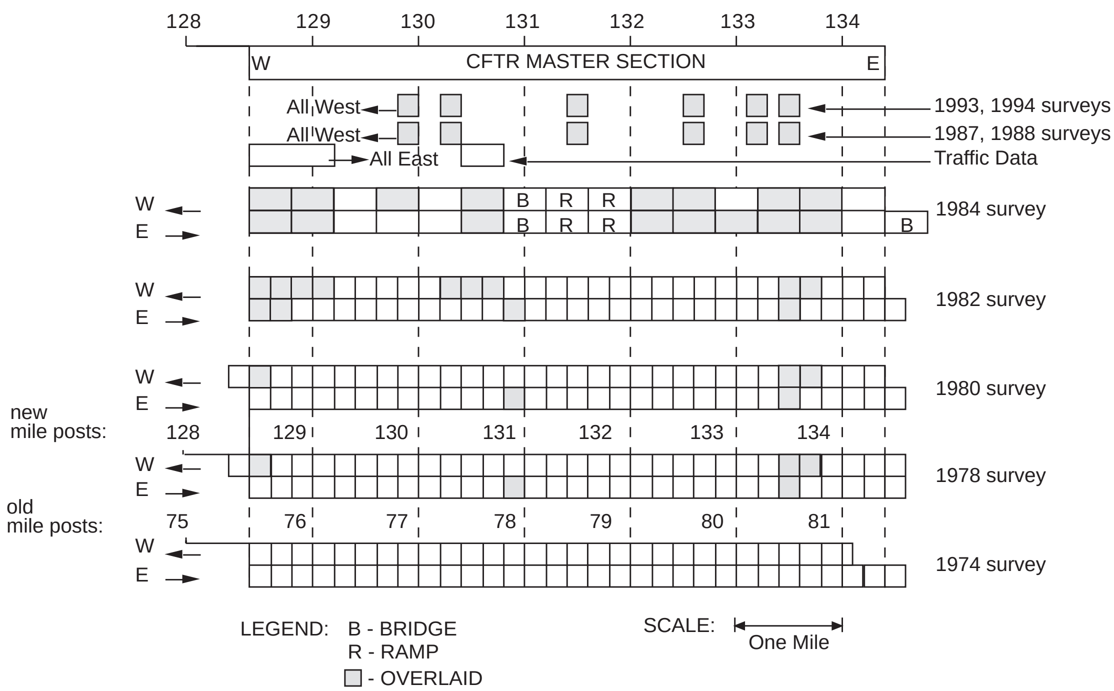

Figure 2.1 Evolution of the CRCP survey locations (1 mile=1.61 km)

2.1.2. The JCP Database

A major effort to reinstate jointed concrete pavements (JCP) into the database was undertaken in 1993. Although JCP had been surveyed in 1982 and 1984, no subsequent surveys have included them and little effort was made to organize and use the initial data collected. The JCP survey locations were all redefined in 1993 under this project, after extensive study and discussion with TxDOT representatives. The locations were selected based on a factorial design developed by Dossey (Ref 10), which was the culmination of a statistical study designed to ensure that the relatively few JCP sections surveyed would adequately represent the state inventory, including a variety of reinforced and plain-jointed pavement designs. An effort was also made to tie in the existing survey data from 1982 and 1984 to the new database, establishing an instant history file for jointed pavements (Ref 8).

At the present time, the CRCP and JCP databases exist in parallel with similar structure and database design — though with no common access mode. One of the goals of this project is to incorporate both sets of data into one comprehensive database.

2.2. HISTORY OF DATA COLLECTION

Responding to the changing needs of pavement research, and with the benefit of experience, the type of distress data collected has also evolved since 1974. The data collection methodology and the types and definitions of the pavement distresses recorded in each survey year have been documented elsewhere (Ref 6). Table 2.1 summarizes the evolution of the CRCP condition survey data.

Table 2.1 Evolution of the CRCP condition survey data

			Condition of Survey							
Distress Type	Type	Intensity	74	78	80	82	84	87	94	96
Cracking	Transverse	Minor	·	·				·	·	·
		Severe	·	·				·	·	·
	Longitudinal		·							
	Localized	Minor	·							
		Severe	·							
Spalling		Minor	·	·	·	·				
		Severe	·	·	·	·	·			
Pumping		Minor	·	·	·	·				
		Severe	·	·	·	·				
Punchout		Minor	·	·	·	·		·	·	·
		Severe	·	·	·	·	·	·	·	·
Patch	AC		·	·	·	·	·	·	·	·
	PCC		·	·	·	·	·	·	·	·
Crack Spacing	Transverse							·	·	·
Reflected Cracks	Overlaid Pavements							·	·	·
Overlay Bond Failure	Overlaid Pavements							·	·	·
Alligator Cracking	Asphalt Overlays									·
Block Cracking	Asphalt Overlays									·
Long. Cracking	Asphalt Overlays									·
Rutting	Asphalt Overlays									·

In a similar manner, Figure 2.2 summarizes the number and type of pavement sections visited during each year a survey was conducted. As can be seen in the figure, CRCP data were collected on nine occasions, and JCP data were collected during just four surveys. For the years prior to 1987, a 100 percent sample of the state's rigid pavements was collected, resulting in more than 4,000 and 6,000 sections of JCP and CRCP, respectively. Although these large data files are still maintained and available, a decision was made in 1987 under Project 472 to reduce the sample rate to about 4 percent. After the 1987 survey sections were chosen, historical data for just those sections were extracted from the older data files and incorporated into the current database. Accordingly, for the years 1974 through 1982, the chart shows the number of sections stored in the database (i.e., not all of the sections collected).

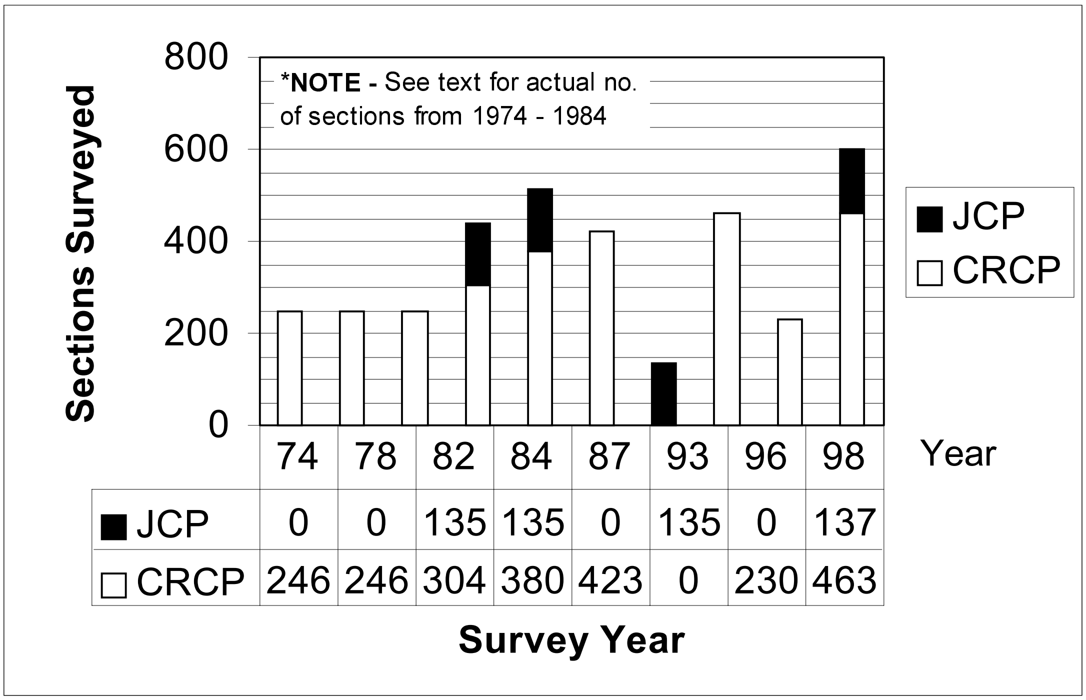

Figure 2.2 Number of CRCP and JCP sections surveyed by year

2.2.1. 1974: Project 21

Data collection for the RP database began in 1974 under Project 21 (Ref 11). As in all subsequent studies up to 1987, an effort was made to collect condition survey data for the entire CRCP network. To make this possible, raters estimated all distresses from a vehicle moving on the pavement shoulder, a procedure that resulted in some loss of accuracy, compared with the present system of walking the pavement. At this time, the 304.8-m (0.2-miles, or 1,000-ft) sampling length was developed that is still in use today (Figure 2.1).

Initial data types collected were transverse cracking, spalling, pumping, minor and severe punchouts, patches, and pavement serviceability index (PSI) (Table 2.1). A detailed description of the data collected can be found in CTR report 472-6 (Ref 5).

2.2.2. 1978: Project 177

In 1978 the same survey sections were revisited, using the same procedure of rating from a moving vehicle on the shoulder (Ref 12). As shown in Table 2.1, a few changes were made in the type of data collected. Estimation of Y-cracking (y-shaped cracks linking transverse cracks) was dropped along with shoulder condition. Spalling, which had been only estimated as a percentage of cracks with spalling, was now recorded as the number of spalled cracks using a mechanical counter for increased accuracy. Also, instead of estimating the length of road affected by punchouts and patches, an actual count of punchouts and patches was made in 1978. This change was made because maintenance costs are affected by the amount of patching material needed to a lesser degree than are start-up costs (i.e., traffic control, equipment mobilization, etc.). Finally, determination of transverse cracking was improved by actually measuring the cracks in a 91.44-m (300-ft) sample section, instead of just estimating the cracked area of pavement from a vehicle.

2.2.3. 1980-1982: Project 249

Under Project 249, survey teams were sent to the rigid pavement sections in 1980 and again in 1982 (Ref 13). In 1980, the condition survey was performed as in the years before, with only minor changes in procedure. Spalling was classified into “minor” and “severe,” and recorded separately. No transverse cracking data were collected that year.

In 1982, the survey was performed in the exact same manner as in 1980. Some of the urban sections were actually surveyed in late 1981 but are labeled as 1982 in the database.

2.2.4. 1984: Project 388

Project 388 brought major changes to the data collection procedure (Ref 14), which were implemented in 1984 and never repeated. First, in order to speed up the survey process, the speed of the vehicle, still driving on the shoulder, was increased from 8 to 24 kmph (5 to 15 mph). The length of the survey sections was also increased from 0.32 km to 0.64 km (0.2 to 0.4 miles). Both of these changes were made to bring the procedure more in line with TxDOT’s (then the State Department of Highways and Public Transportation) evolving procedures for the new Pavement Evaluation System (PES) database. Prior to this decision, a study was undertaken to determine the effect of speed on data collection; that study indicated that, at the higher speeds, changes in the survey results are inconsequential.

Recording of the field data was complicated by the deployment of a third person in the vehicle. This third person was assigned to operate a Macintosh personal computer that had been adapted for portable use through hookup with the car’s battery. Data were recorded by the operator directly to diskette (hard drives were not yet available for personal computers) to avoid the additional effort and possible inaccuracies caused by data transcription from survey forms. Although this procedure could today be easily undertaken using currently available laptop and palmtop computers, it was quite a challenge in 1984; nonetheless, the set up worked surprisingly well.

As far as distress types collected, only spalling, number of severe punchouts, and number of patches in the outside lane were recorded. And only the severe punchouts were recorded, since they lead directly to maintenance needs. Furthermore, it was ascertained that the severe spalls were not an evolution of the minor spalls, but rather involved two different mechanisms. Severe spalls were found to be a function of construction, whereas minor spalls were deflection related and were not an extensive problem. The data were collected in the outside lane, as prior analysis indicated that the majority of repairs take place in that lane.

2.2.5. 1987: Project 472

Project 472 brought the most profound changes to the database and collection procedures, including the introduction of the current practice for data collection and storage (Ref 9). First, and most importantly, a decision was made to no longer survey the state's entire inventory of rigid pavements. Instead, a statistical study was performed to develop a sampling template or factorial design to identify a small sample of the total sections that would adequately represent the overall population. The sampling procedure used was a two-step process. First, approximately 300 paving projects across the state were selected to provide a representative sample of pavement types, thicknesses, aggregates, age, overlay status, and climatic environments. A "project" is a length of pavement constructed at the same time with the same design and, therefore, assumed to be homogeneous in terms of performance. Next, up to six survey sections were selected out of each project. Another part of the collection procedure modification was a decision to retain the section length of 304.8 m (0.2 miles, or 1,000 ft) used in most of the previous surveys. To study the effect of grading on performance, two sections (where possible) were selected from "cuts," two from "fills," and one each from "grade" and "transition."

Because the sample was so much smaller than the population, rating from the vehicle was abandoned and two raters were employed to perform the survey on foot. The smaller sample size also enabled greater detail in distress measurement. Specifically, the raters now counted the number of cracks for the entire section; additionally, they recorded a Rolotape measurement of the exact spacing of the transverse cracks in the first 61 m (200 ft) of the section. Punchouts and patches were recorded in greater detail, with the survey now including the size as well as the number.

By 1987, the state's inventory of rigid pavements had experienced some aging and wear, necessitating a number of overlaid sections. To monitor the performance of these composite pavements, a second rating form was developed that included reflected cracks (number and spacing), bonding failures, and patches.

Finally, as a one-time study (still under Project 472), a structural evaluation was conducted of many of the test sections using the falling weight deflectometer (FWD), a device that strikes the pavement with up to 9 metric tons (20,000 lb) of force, and then measures the resulting deflections at various intervals using geophones. Analysis of the resulting data can approximately determine the stiffness of the pavement and underlying layers, and thus give some indication of the remaining fatigue life. A thorough description of the data obtained and some subsequent analysis can be found in CTR report 472-5 (Ref 15).

2.2.6. 1994: Project 1342

After a seven-year hiatus, data collection was resumed in 1994 following a plan developed for TxDOT under study 187-7 (Ref 10). The 187-7 study developed a new collection factorial for the RP database that now included jointed reinforced concrete (JRC) and jointed plain concrete (JPC) pavements for the first time since 1984. The purpose of the new factorial was to keep the RP database useful by including sections newly designed with double-matted steel and having pavement thicknesses greater than 25 cm (10 in.). In addition, factors identified in other studies as possibly related to performance (such as coarse aggregate type, slab length for jointed pavements, etc.) were included after discussion with TxDOT and other experts.

An important consideration for the Project 1342 study was the relationship of the RP database to TxDOT's emerging Pavement Management Information System (PMIS). The PMIS is "an automated system for storing, retrieving, analyzing, and reporting information to help with pavement-related decision-making processes" (Ref 1). As explained in Chapter 1, the RP database provides essential data for the development of performance models needed by the PMIS. Since a concurrent study indicated that insufficient data were available to adequately model the performance of composite or overlaid pavements (Ref 2), an additional emphasis was placed on resurveying these sections under Project 0-1342.

2.2.7. 1996: Project 2952

Project 7-2952 is the current study charged with updating and expanding the RP database. Goals for this study include:

(1) Reviewing and revising the sampling factorial to ensure that the RP database continues to be a representative sample of the Texas rigid pavement population

(2) Updating important inventory data, such as date of overlays, cumulative traffic exposure, climatological data, etc.

(3) Developing a method for permanently and accurately marking the survey sections

(4) Revising the database as needed to maintain compatibility with PMIS

(5) Updating traffic and drainage models previously derived from the database with current information

(6) Providing better accessibility to the database from a wide base of PC platforms and software

2.3. SUMMARY

The RP database has undergone many changes since its inception in 1974. What began as a network database with sketchy coverage of all the rigid pavements in the state has become a project-level, research database with detailed coverage of a small but representative sample of these pavements. Approximate, subjective assessments of distress made from a moving vehicle have been superceded by more precise measurements made on foot with Rolotape, tape measures, and crack-width gauges. The data, once stored in large text, FORTRAN-style files, have now been organized into a modern database structure. Statistics, trends, graphs, modeling, and forecasts using the data can now be made in minutes using the built-in SAS functions.

The information and references in this chapter are provided partly as a history of the database development for the interested reader. It is most important, however, that this information be considered by anyone using the database for research. It is essential to take into account the changing data types, collection procedures, sampling rate, distress definitions, and degree of measurement precision employed each survey year when constructing a distress history of a project or section from the database. For instance, spalling data taken as percentages in 1974 cannot be directly compared with the number of spalled cracks collected in 1978 without converting the data into similar units. The number of punchouts observed in 1984 may seem to stand out from the historical trend — until it is remembered that the 1984 sections were 643.7 m (0.4 miles) instead of the standard 304.8-m (0.2-mile) sections. Every effort has been made — and is being made — to standardize the database content, but some caution must be used in interpreting the data, especially those obtained in survey years prior to 1987.

CHAPTER 3. DATA COLLECTION PLAN

3.1. INTRODUCTION

As has been established in Chapter 1, the current function of the database is to support research relating to long-term pavement performance. In order to do that, detailed performance and inventory data must be collected from a representative sample of the state's rigid pavement network over a period of time corresponding to the life cycle of pavements (approximately twenty to thirty years). The performance data (distress, serviceability, etc.) then become the dependent data available for modeling, while the inventory data (pavement thickness, traffic loadings, environmental factors, etc.) are the independent variables that can hopefully be employed to explain and predict the differences in performance observed between sections.

Because new pavement designs and specifications are being developed, and because additional factors are being identified that affect performance, the data collection plan or factorial design must be changed from time to time to maintain and improve the usefulness of the database. The database history summarized in Chapter 2, tracing the gradual evolution of the database objective and organization from management at the network level to research at the design level, shows that a number of changes have already taken place regarding the survey procedures and the types of data collected. The last such change has emphasized collecting data from overlaid pavements, incorporating additional distress types to support the TxDOT PMIS distress recommendations for revising the sampling factorial to be used beginning with the 1996 survey.

3.2. CURRENT DATABASE DEMOGRAPHICS

An examination of the current database demographics (as of January 1, 1995) reveals several problems that need to be corrected in the next survey, if possible.

3.2.1. Pavement Thickness

The first and most problematic imbalance in the collection factorial is pavement thickness. Prior to the 1990s very few thick PCC pavements were being built in Texas; even today the great majority of CRC pavements in service are 20.3 cm (8 in.) thick. This anomaly resulted from an FHWA policy in effect from the late 1950s to the 1980s prohibiting construction of CRCP greater than 20.3 cm (8 in.) thick. This policy was revised by the justification of the 33-cm (13-in.) CRCP on IH-35 adjacent to the Fratt Interchange in San Antonio. The population of the RP database reflects this. Figure 3.1 shows that nearly 90% of the CRCP sections surveyed in 1994 were 20.3-cm (8-in.) pavements.

Because the data collection factorial for jointed pavements was revised as recently as 1994 (Ref 8), no comparable problem for JCP exists. A study in 1993 (Ref 10) that established the JCP factorial determined that the median thickness for both jointed plain and jointed reinforced pavements in Texas is 25.4 cm (10 in.). This thickness was therefore selected as the dividing value for thickness, and an effort was made to select an equal number of survey sections on either side of that value. Figure 3.2 shows the resulting distribution as collected by the survey teams. Note that approximately 50% of the database sections were less than 25.4 cm (10 in.) thick, and an equal percentage were 25.4 cm (10 in.) or greater.

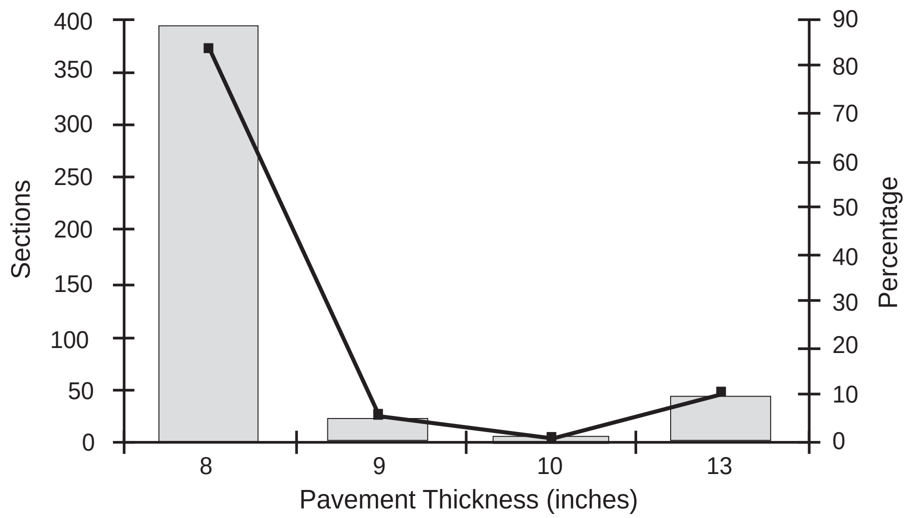

Figure 3.1 Distribution of CRCP thickness (1994)

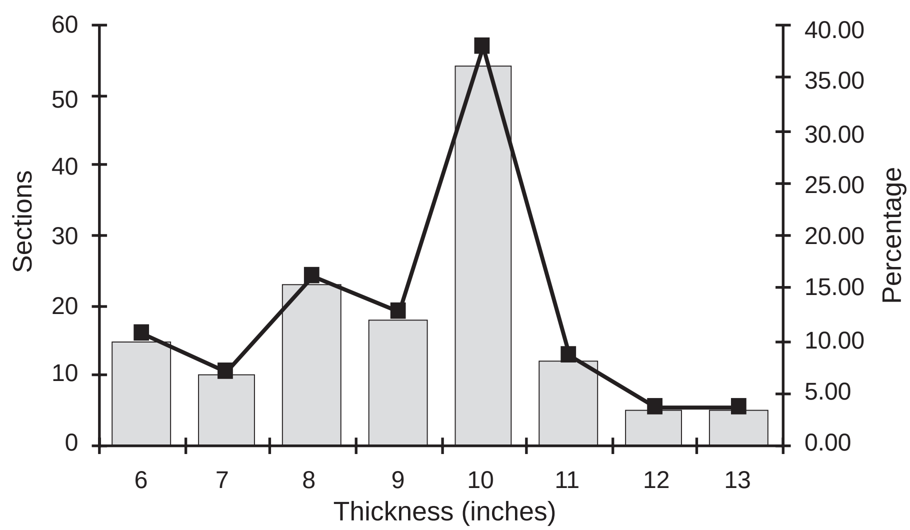

Figure 3.2 Distribution of JCP thickness (1994 survey)

Based on these observations, an effort should be made to identify and collect additional CRCP sections having thicknesses greater than 20.3 cm (8 in.). Some sections of 20.3-cm (8-in.) pavement could be dropped, if necessary, to facilitate data collection on the additional sections. Identification of "thick" candidate sections will be discussed later in this chapter.

3.2.2. Pavement Age

Another area of potential concern is pavement age: The Texas rigid pavement population is aging, and that is reflected in the database. However, for modeling purposes, observations are needed that show the development of distress at early ages, since determining the cause(s) of early pavement failure is a high priority. Some data of this sort are already available: Observations from the database taken in 1974, for example, when the average age of Texas' rigid pavements was 6.76 years (median 6.42 years), have proven useful in PMIS modeling of early-age distress (Ref 2). Considering the CRCP data in this fashion, for example, the age distribution looks very satisfactory (Fig. 3.3). But there is some cause for concern in that models developed from data collected twenty years ago may not adequately reflect the performance of current design and construction practice.

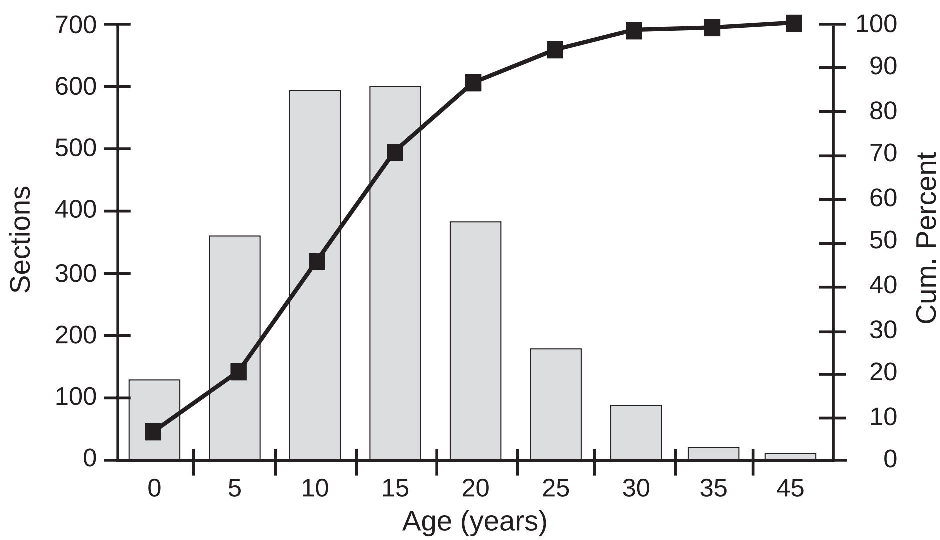

Figure 3.3 Age distribution of all CRCP data points (1974-1994)

Figure 3.4 shows the age distribution of the survey sections at the end of 1994. In contrast to Figure 3.3, it can be seen that the majority of CRCP survey data currently being collected are from pavements greater than twenty years old. If no adjustments are made, the 1996 and, presumably, 1998 surveys will find this distribution shifted to the right an additional two and four years, respectively. Obviously, an effort should be made to identify and survey newer pavements, preferably from the year they are placed onward. Pavement projects utilized in the development of the QC/QA specification for PCC represent excellent candidates, given that extensive material properties, environmental factors, and geometric information have been documented.

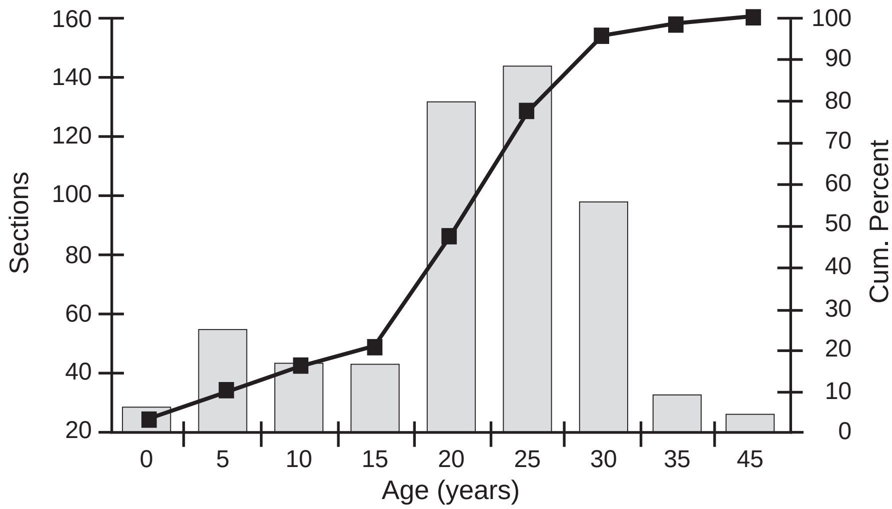

Figure 3.4 Age distribution of CRC pavements surveyed in 1994

3.2.3. Overlaid Pavements

Overlays represent the final area of concern. With the aging of the database sections, more and more of the sections have been overlaid. These sections should continue to be surveyed as they provide important data on composite (asphalt over PCC) pavements that are available from no other source. Also, as these pavements begin to comprise the majority of the state's rigid pavement inventory, the ability to predict their performance will become correspondingly more important in managing the network.

From the previous discussion, it is equally important to collect data from newer, nonoverlaid pavements; it is therefore necessary to maintain a balance in the database between the two. Table 3.1 shows that the current database demographics indicate a good balance between overlaid and nonoverlaid pavements, nearly equal in number. All that is necessary, then, is to continue to collect from existing sections and to add new sections as they are identified.

Table 3.1 Overlaid vs. nonoverlaid CRCP (1994 survey)

Status	Frequency	Percent
NONOVERLAID	253	51.5
OVERLAID	238	48.5

Again, reflecting the recent factorial redesign, the JCP portion of the database is in good shape, with 56% nonoverlaid vs. 44% overlaid (Table 3.2). In the next few data collection cycles, the balance will shift closer to even, as more of the sections are overlaid.

Table 3.2 Overlaid vs. nonoverlaid JCP (1994)

Status	Frequency	Percent
NONOVERLAID	81	55.9
OVERLAID	64	44.1

3.3. REVISION OF DATA COLLECTION FACTORIAL

Using the above analysis, a revised collection plan can be developed. This plan will be put into effect for the 1996-1997 data collection period and will be revised at the end of that period, assuming that additional funding for field surveys is forthcoming. The plan will include the following elements:

(1) No additional data collection on 20.3-cm (8-in.) nonoverlaid pavements this year
(2) All data collection on existing sections will be on asphalt-overlaid CRCP
(3) No collection on jointed pavements this year (comprehensive collection last year)
(4) Continued collection on CRCP thicker than 20.3 cm (8 in.)
(5) An effort to identify and collect data on new CRCP
(6) Inclusion of existing survey data from other TxDOT projects studying CRCP
(7) Add to RP database all RP sections with new design or construction elements

3.4. CHANGES IN DISTRESS VARIABLES

As discussed in Chapter 1, it is also important to periodically assess the types of distress information collected, and to review the importance and feasibility of collecting each data item. Table 2.1 shows the data types to be collected during the 1996-1997 survey. As shown in the table, the choice of condition survey data types (as opposed to inventory data types) is recommended to continue with the 1994 items, with the exception of the following added data types for asphalt overlaid sections:

(1) Alligator cracking — Collected as a percentage of the total wheelpath area in the right-hand or travel lane
(2) Block cracking — Collected as a percentage of the total surface area of the rated lane
(3) Longitudinal cracking — Collected as the number of overlaid slabs (as closely as can be determined) that exhibit longitudinal cracking in the asphalt overlay

(4) Rutting — Collected as a percentage of the wheelpath area, divided into categories of “shallow” (between 1.27 cm [0.5 in.] and 2.54 cm [1.0 in.] in depth) and “deep” (greater than 2.54 cm [1.0 in.] in depth)

These changes are reflected in the new rating form that is included in the appendix. Rating of the percentages in the above four items is approximate, as estimated visually by the rater without the use of any special measuring equipment.

3.5. ADDITIONAL INVENTORY VARIABLES

As discussed previously, inventory data are comprised of information relating to the construction, traffic exposure, design, location, and environmental (climatic) conditions relevant to the pavement — i.e., everything that is not a measurement of distress or performance. Many inventory items remain constant or nearly constant over the life of the pavement (e.g., construction date, subgrade soil type, and average yearly minimum temperature). Other items, including average daily traffic, presence or absence of overlay(s), etc., change substantially. Inventory items are also added or deleted from the collection process as research identifies them as more or less important to pavement performance, and as new technology allows improved accuracy (e.g., location identification by GPS receiver.)

After examining the current database, we recommend that additional or updated inventory data be collected in the areas identified below.

3.5.1. Overlay Dates

Overlay date is an essential indicator of pavement performance. Although nonpavement-related considerations also play a part (budgetary constraints, policy, politics), the decision to overlay generally is triggered by the pavement condition dropping below a threshold level of some distress or performance indicator; thus, the time or traffic exposure occurring between construction and the date of first overlay is an estimator of the as-built life of the pavement.

The presence of an overlay is recorded in the database in two ways: First, the rater visiting the section chooses a survey form for overlaid sections, resulting in the section being tagged as overlaid in the database; second, a periodic inspection of district records is made by the project team to determine which sections in the district have been overlaid since the last such inspection. This is done by comparing the TxDOT control and section numbers from a list of database sections to the “as-built” book in the TxDOT district office. Information from this form is then input into the inventory data for the RP database. Each new overlay is recorded as a date in the database variables “OV1-OV4.”

The two methods of determining overlay status serve as a cross-referencing check. Periodically, a program is run against the database to compare the two overlay indicators. Inconsistent sections are pulled and corrected if possible. If no resolution is available, the observation of the field crew is assumed to be correct, since district records are sometimes spotty or difficult to obtain.

It is important to maintain the inventory file’s overlay dates and not rely solely on the rater’s assessment for another reason: Field surveys do not occur every year, so without the “exact” date of overlay from the district, the determination of pavement life would be much more imprecise.

The last update of overlay dates from district records occurred in 1987 (Ref 9). It is therefore recommended (and planned) that each district headquarters be visited to update this information during the 1996-1997 survey period.

3.5.2. Expanded Climatic Data

Recent studies have shown that climate has a significant effect on pavement performance (Refs 2, 4). In Texas, where frost heave is not a great concern, the primary considerations for environmental effects are rainfall amounts (especially where swelling soils are present) and evaporation rate and peak summer temperatures during PCC placement. The first annual low temperature experienced by a PCC pavement after construction also has a pronounced effect on early-age cracking and long-term performance.

Currently, the RP database contains only two climatic indicators (Ref 5): average lowest annual temperature, and average annual rainfall amount. Using only these two variables, it is impossible to calculate evaporation rate, low winter temperature after placement, or high ambient temperature during placement. Studies using the database have generally ascertained the potential for swelling damage by correlating swelling soils with high rainfall, or by using the average low temperature as an input to analysis programs like CRCP8 (Ref 16); anything else has required additional climatic data from an external source.

In order to improve the database usefulness and to widen its applicability to studies such as those cited above, the inclusion of additional climatic variables in the database is planned. The National Oceanic and Atmospheric Administration (NOAA) maintains comprehensive climatic databases that are available on CD-ROM. These data will be purchased and merged with the database, creating the following variables:

(1) Average minimum annual temperature — Updated from the 1987 numbers currently in the RP database

(2) Average annual rainfall — Updated from the 1987 numbers currently in the database

(3) Average monthly evaporation rate — Mean evaporation rate for each month averaged over ten years, by county, for matching with the survey sections

(4) Low temperature after construction — Minimum temperature experienced *by each project* within the first year of pavement life

(5) High temperature during construction — Average highest daily temperature during the month of construction *for each paving project in the database*

Note that items 1, 2, 4, and 5 are calculated for each project and stored with the inventory data. Most of these data are easily obtainable from the NOAA CD-ROM, using the weather station nearest to the project. Item (*5)* is the most problematic because the construction dates in the RP database are taken from imprecise TxDOT records and may be several months *early* since they are more a record of contract letting than actual construction starts. An effort will be made to improve the construction date precision prior to summarizing the NOAA files.

Despite the above limitations, adding climatic data according to this plan will result in a significant improvement in the database applicability to a number of ongoing research studies — studies whose objective is to demonstrate that a project's overall performance is highly related to the climatic conditions during construction.

3.5.3. Traffic Data

Traffic loading is one of the most significant causes of pavement deterioration, but one of the most difficult to measure. Currently, the RP database contains traffic data from two sources: the TxDOT yearly Average Annual Daily Traffic (AADT) maps and the TxDOT Roadway Information File (RIFILE), formerly known as the RI2TLOG.

ADT maps are produced by TxDOT yearly, giving ADT data for more than 75,000 pavement sections across the state. The data are recorded primarily by using Accumulating Count Recorders (ACR), the familiar rubber tube stretched across a road. Continuous counts are taken on only a few pavement sections; most sections are sampled only once per year for a 24-hour period. Approximate seasonal adjustments are then made to the databased analysis of the continuously monitored pavements. At the end of the year, the data are averaged and posted to the map known as the "annual average map." An excellent description of the hardware, software, and procedures used, as well as additional references, can be found in CTR report 2010-1F (Ref 17).

TxDOT AADT maps covering the period from 1975 to 1985 were used by Project 472 in 1987 to provide the 1985 ADT and ten-year average growth rate for each of the projects in the database. These two numbers are stored as ADT85 and G in the inventory file (Ref 5); most of the projects in the RP database include these data.

In addition to the ADT data, expanded traffic data, including yearly percent trucks, average ten heaviest wheel loads, percent tandem axles, and two-way equivalent single axle loadings (ESAL) data are available for some of the projects. These data were extracted from TxDOT weigh-station records by Project 1169 personnel (Ref 18). Because that study was trying to determine the number of axle loadings to failure, the data for each project contain yearly observations from construction of the pavement to the time of first overlay. These data are available only for selected projects in the database (less than 10% of all projects). Nevertheless, sufficient data were available to develop four traffic models that can be used with varying degrees of confidence to estimate ESAL numbers for the remaining sections in the RP database (Ref 5).

In light of the above discussion, the following plan will be implemented to update the traffic data in the database:

(1) AADT will be updated for the first time since 1987 by requesting all available traffic maps from 1986 to the most recent data available. Instead of assuming a linear growth rate, as was done in 1987 (Ref 9), a log/exponential model will be fit through each section's twenty-year history, and the coefficients of the log model will be stored in the inventory section of the database.

(2) A map showing the location of existing and planned weigh-in-motion (WIM) sites will be obtained from TxDOT. Where WIM sites occur on or near rigid pavements, additional database sections will be added to the collection factorial so that some survey sections will have detailed traffic data available.

(3) The 1987 traffic models estimating ESALs from ADT and other more readily obtainable variables will be updated and recalibrated with the new WIM site data and additional AADT data.

3.5.4. Location of Drainage Improvements

Recent interest has been expressed at the federal level regarding the effect of improved drainage on pavement performance. It is thought that some TxDOT districts have pavements built with french drains (gravel structures that drain some of the moisture from the subgrade). During the 1996 survey, survey teams collecting overlay dates at the district offices will also attempt to determine the location of any improved drainage beneath rigid sections in the district.

3.5.5. Improved Section Location Data

The precise location of the survey sections is essential to the integrity of the database. If the sections cannot be located within a reasonable margin of error after a period of two to ten years, the distress curves stored in the database will not be consistent. In some cases, a location error of 30.48 m (100 ft) would cause an apparent “healing” of the pavement from the previous survey, with no known maintenance action to support it. Conversely, a 30.48-m (100-ft) shift in the other direction might increase the apparent distress significantly. These types of anomalies would not be distinguishable from rater error or unrecorded maintenance activity once the data had been added to the database; they would also increase variability in any model developed from the data.

Methods of marking the sections have varied through the survey years, usually involving mileposts or reference markers and paint. Halfway through the 1994 survey, a global positioning system (GPS) receiver was employed in tandem with the existing procedures as an experiment to determine if GPS technology was sufficiently mature and applicable to pavement section location. The results of this experiment, a general discussion of pavement section location, and recommendations for locating the sections in future surveys are given in the next chapter.

CHAPTER 4. PAVEMENT SECTION LOCATION

4.1. NEED FOR PRECISE SECTION IDENTIFICATION

As mentioned in Chapter 3, accurate relocation of the survey sections from year to year is essential for maintaining an accurate performance history of the pavements in the database. If the section of a highway surveyed varies substantially from year to year, the apparent distress history will vary upwards and downwards, depending on the condition of the beginning and ending segments of the survey section. For example, if the initial 61 m (200 ft) of a section contain an above-average amount of damage, accidentally excluding it from the survey would cause the average condition of the section to show an apparent improvement. An incorrect location in the opposite direction might include more of the damaged pavement, raising the average distress of the survey section.

In extreme cases, where some sections but not all of the pavement project are overlaid, mislocation from year to year might cause the section to be identified as overlaid one year and nonoverlaid the next. This is rare but troublesome, since it cannot be distinguished from rater error after the data have been entered in the database. Overlay status is the prime indicator used to determine pavement life and, thus, to calibrate models predicting pavement life.

4.2. CURRENT SYSTEM

Prior to the 1996 survey (the time of this writing), the existing method of identifying the pavement sections consisted of three parts: (1) TxDOT control, section, and job numbers to locate the overall paving project and to match with TxDOT records; (2) district, county, highway, and milepost data to locate the survey section within the paving project; and (3) paint markers on the highway to assist in the identification of the precise starting and ending points from survey to survey.

Several problems exist with this system. First, over time the paint markers become increasingly difficult to find as a result of wear, the effects of sun and rain, and sometimes new construction or an overlay. Since funding for condition surveys is sometimes sporadic, the long intervals between surveys may render the paint markers unreliable. This was particularly troublesome in the 1994 survey, which required visiting many sections that had not been rated since 1987.

Also, because mileposts change, the use of mileposts and displacements from mileposts has not been found to be reliable over the years. Mileposts are not always located near a survey section, and, except for the interstate highway system, mileposts are not readily convertible into the reference marker system now becoming standard at TxDOT and used in the TxDOT PMIS. These problems have resulted in pavement raters resorting to such location descriptions a “1000 ft from the Burger King entrance," which might or might not prove to be repeatable in subsequent surveys.

4.3. PROPOSED SYSTEM

In order to resolve the above-mentioned problems and improve the accuracy and repeatability of section location, the following procedure will be implemented beginning with the 1996 survey:

(1) The current project-level identification using control, section, and job will be retained to facilitate matching with construction records and older TxDOT data files.
(2) Use of mileposts will be discontinued and reference marker location will be determined and recorded for each section in the database as they are revisited.
(3) A global positioning system (GPS) satellite receiver with differential correction will be obtained and the data recorded in parallel with the current identification process until the GPS has been evaluated (see next section).
(4) The use of paint markers will be continued, partly to visually confirm GPS location and partly to provide ease of location when sections are visited regularly.

4.4. EVALUATION OF GPS

Small, inexpensive GPS satellite receivers are now readily available. The simplest receivers can be purchased at sporting goods stores for approximately $150; differential-capable receivers, featuring a connection port for FM differential correction receivers, are a little more expensive but still well under $500. Since these devices are now easily affordable and within the study budget, a brief analysis of their usefulness in locating RP database sections is in order.

4.4.1. GPS Concepts

GPS is a space-based, radio-navigation system developed by the U.S. Department of Defense. It was designed to allow a soldier to determine his position within 10 to 20 m using a single, one-way receiver without any other communication that could potentially be detected by hostile forces. The system was designed to provide worldwide coverage, 24 hours a day. At the same time, the system had to be developed such that the U.S. military had the ability to deny use by any hostile group without degrading their own use.

GPS is only one of many past and current radio-navigation systems. There are at least a half-dozen different radio-navigation systems in use today, including Omega, Loran, VOR/DME, ILS, Transit, and GPS. Ground-based radio-navigation systems such as Omega and Loran use very low-frequency, long-wavelength carrier waves and employ difference-of-arrival techniques to determine the location of a receiver. These long-wavelength signals are able to "tunnel" through the atmosphere by bouncing off the bottom of the ionosphere for great distances. This phenomenon is known as wave form ducting. This method is so effective that complete global coverage is achieved by Omega using only eight transmitters. The disadvantage to these systems is that they achieve very low precision owing to the long wavelengths. The potential error for these systems is 6 km (3.73 miles) for Omega and 4.5 km (2.8 miles) for Loran.

VOR/DME (Very High Frequency Omnidirectional Ranging/Distance Measuring Equipment) and ILS (Instrument Landing System) are used by aviation and are much more precise because they operate at a much higher frequency. The theoretical precision of these systems is on the order of 60-80 m (197-262 ft) for VOR/DME and less than 10 m (33 ft) for ILS. The disadvantage to these systems is that they require a line-of-sight to the receiver. The higher frequencies employed by these systems punch through the ionosphere rather than bouncing off, as do the lower-frequency, longer-wavelength signals of other ground-based radio-navigation systems. This line-of-sight requirement makes it useful only to receivers that are in the air, since all of the transmitters are ground based.

GPS is the highest frequency, shortest wavelength, and, consequently, the most precise system ever developed. GPS became fully operational in July 1995 with a full constellation of twenty-four satellites operating in six earth orbits. These satellites orbit at an altitude of approximately 20,200 kilometers (12,500 miles) — about half the altitude of geostationary satellites. GPS satellites complete one orbit every 11 hours and 58 minutes.

As shown in Figure 4.1, the global positioning system has three basic components: the space segment, the control segment, and the user segment. The space and control segments are operated by the U.S. military and administered by the U.S. Air Force's U.S. Space Command. The space segment consists of all GPS satellites currently in orbit, including operational, backup, and inoperable units. The control segment maintains the integrity of the satellites and the data they transmit. The user segment is comprised of all of the end users having GPS receivers.

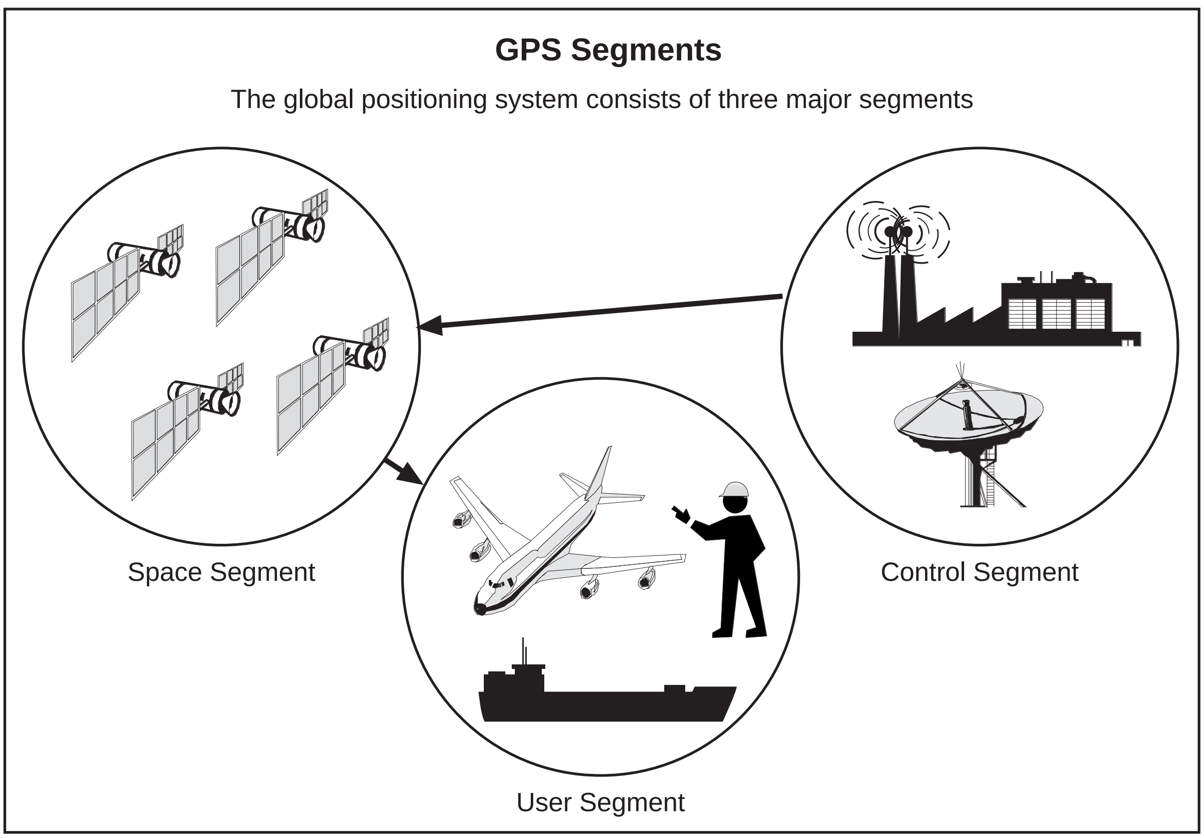

Figure 4.1 Segments of the GPS

The control segment (Fig. 4.2) consists of one Master Control Station (MCS) located at Falcon Air Force Base in Colorado Springs, Colorado; five unmanned monitor stations, located around the world; three primary ground antennas, located more or less equidistant around the equator; and two backup Master Control Stations, located in Sunnyvale, California, and in Rockville, Maryland.

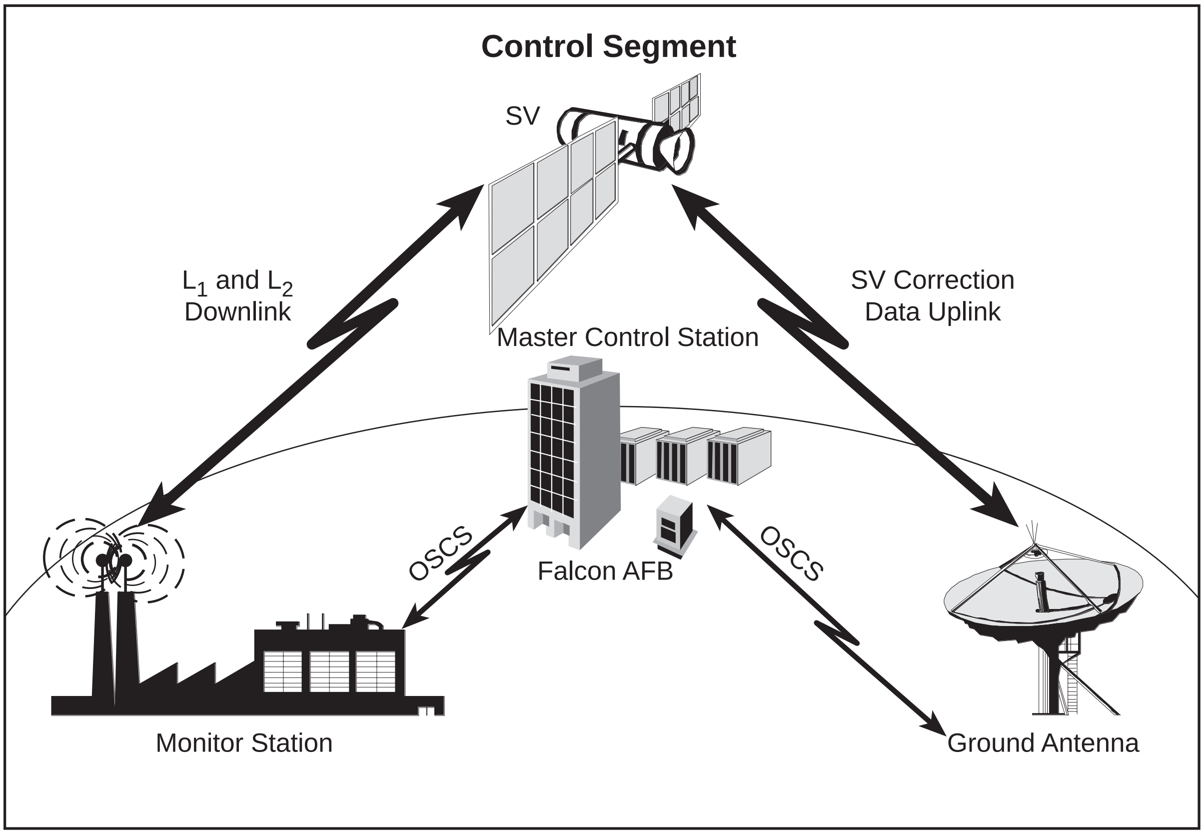

Figure 4.2 GPS Control Segment

The unmanned monitor stations passively track all GPS satellites visible to them and collect ranging data from each. The data are passed via the secure Defense Satellite Communication System (DSCS) to the MCS, where the satellite position and clock timing data are estimated and predicted. The MCS sends corrected position and clock-timing data to the appropriate ground antennas that upload the data to the satellites. The satellites use the corrected information to transmit longitude and latitude data down to the receivers (end users).

The coordinates sent to the receiver are arrived at through a process called *satellite ranging*. The basic concept behind satellite ranging is very simple. Let's say you are at a given location trying to determine the longitude and latitude of your position. If you know that you are 4 km (13,000 ft) from a certain satellite, that narrows down your position to a sphere, centered on that satellite with a radius of 4 km (13,000 ft). If at the same time you know that you are 3.3 km (11,000 ft) from a second satellite, you now know that you are also on a sphere, centered on this second satellite, with a radius of 3.3. km (11,000 ft). Now, the only place in the universe that you can be is on a circle where these two spheres intersect.

If you get a measurement from a third satellite indicating that you are 3.66 km (12,000 ft) away, there are only two points in space where that can be true. Those two points are where this 3.66-km (12,000-ft) sphere intersects the circle created by the intersection of the 4-km (13,000-ft) and 3.3-km (11,000-ft) spheres from the first two satellites (Fig. 4.3). In order to decide which one of these points is the true location, we could take a fourth measurement from another satellite. Usually, however, one of the points is absurd and can be eliminated. The point may not be close to the earth or it may have an impossibly high velocity. GPS receivers have various techniques for determining the correct point. There is another reason for this fourth measurement, however. The fourth measurement ensures that the receiver clock is synchronized with universal time.

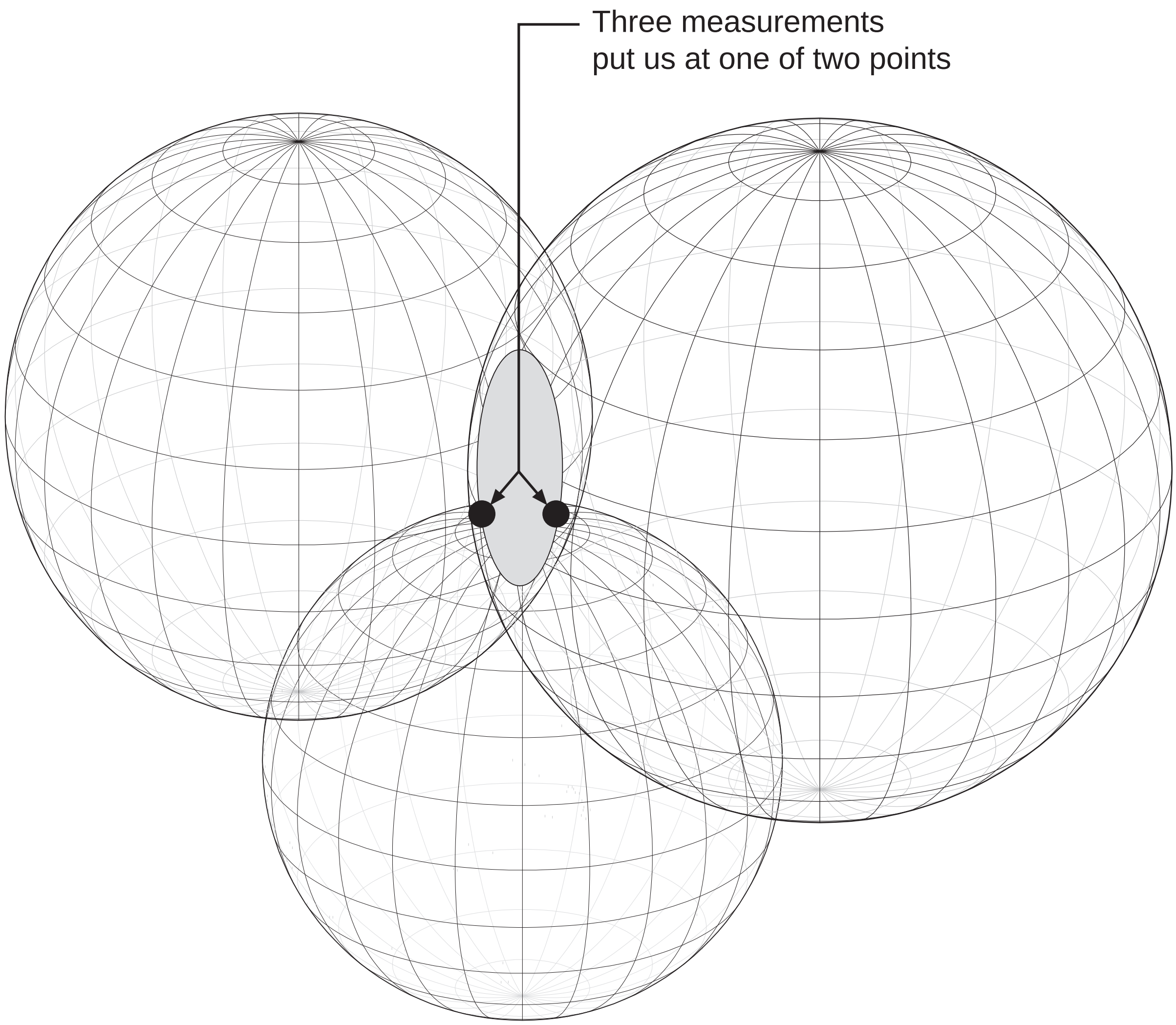

Figure 4.3 Illustration of GPS triangulation concept

4.4.2. Overview of Existing Hardware

GPS receivers generally fall into one of three very broad categories: coarse positioning, mapping, and survey grade. Coarse positioning receivers are at the lowest end of cost and capability. They are usually single- or dual-channel. The number of channels a receiver has determines how many satellites it can collect data from simultaneously. Since at least four satellites are required to calculate a 3-D position location, these receivers rapidly switch among the visible satellites. This is called *fast multiplexing*. These units generally do not have differential correction and do not use carrier smoothing (i.e., a signal processing method used to increase the accuracy of positioning by smoothing the variability in individual positions within a sequence of positions). Selective availability (SA) accuracy of these receivers is approximately 100 m (328 ft). Because of the low cost of these units, they are used for a wide range of consumer applications.

Mapping systems are much more accurate and, therefore, have a wider range of application. The greater accuracy is principally achieved through their differential correction capability. If these receivers have carrier smoothing, they can achieve accuracies within the 3-to-5-m range when utilizing differential correction.

Survey grade receivers can cost as little as $6,000 for single-channel units capable of decimeter accuracy. The highest-end multichannel, geodetic units can cost more than $50,000.

At the time of this writing, two classes of GPS receivers were available in a price range affordable by this study. The specific GPS units described below are typical of all units in the two price categories.

GeoExplorer

For about $2,000, a GeoExplorer GPS receiver can be purchased with an ACCQPOINT FM differential correction receiver to obtain precision down to around 5 m. The GeoExplorer receiver is a high-performance, six-channel, handheld mapping receiver. It is a battery-powered unit designed for portable field use. With this receiver, you can navigate and also store position and attribute information for point, line, or area features. The standard GeoExplorer system includes the receiver, receiver case and lanyard, AA battery pack, data-download cable, GEO-PC software and software key, and documentation. The ACCQPOINT system connects via a computer port and provides the differential corrections for survey sections in all parts of the state.

Trimble Scout

For about $600, a simple GPS receiver such as the Trimble Scout can be purchased. Like the GeoExplorer, it is a handheld coarse positioning device with about 100-m (300-ft) accuracy. Unlike the GeoExplorer, the Scout is a low-cost, consumer-level unit that is not differential-correction capable (no computer interface of any sort). Nevertheless, the Scout's performance in the field in the previous study (Project 1342) was a marked improvement over that of the existing system for section location, especially in those cases where the paint marks had been eradicated.

4.4.3. Theoretical Precision of GPS

In order to determine which system best suits the project requirements, it is first necessary to examine the precision of the instruments and the needs of the project. GPS is the most accurate global navigation system ever developed. However, the ultimate accuracy of conventional GPS measurements is limited by the existence of several error sources within the system. For typical GPS receivers and under good conditions, the best position accuracy that you can expect is 106 m (350 ft).

It will never be possible to eliminate all of the errors in the system. GPS satellites are equipped with very accurate atomic clocks, but these clocks are still not perfect and inaccuracies in their timekeeping ultimately lead to inaccuracies in position measurements. The earth's atmosphere is another cause of inaccuracies in position measurements.

Radio signals in the earth's atmosphere do not behave predictably. Radio waves travel at the speed of light and the speed of light is different in different layers of the atmosphere. Calculations of distance assume a constant speed of light, resulting in slight errors in the distance to the GPS satellites (ranging errors) that translate into errors in position. Good receivers will perform a correction for the trip through the atmosphere, but since the atmosphere is variable from point-to-point and even from moment-to-moment, no correction factor can accurately compensate for these variations.

Multipath errors, as well as errors introduced by receivers, cause further inaccuracies in position measurements. Multipath errors are caused by the reflection of the GPS signal off local obstructions as it reaches the earth's surface. In this case, the antenna will receive the direct signal, because the direct route is always fastest, and then receive the reflected signal fractions of a second later. The delayed signals interfere with the direct signal and give "noisy" results.

By far the greatest source of error in GPS position measurements is caused by selective availability (SA). SA is an intentional error introduced by the U.S. Department of Defense (DoD). DoD introduces "noise" into the GPS satellite clocks and also may give the satellites slightly erroneous orbital data that would be transmitted back to receivers on earth. If you plot the output of a stationary receiver while SA is in effect you would see its position wander around within about a 100-m (328-ft) circle. Military receivers contain a decryption key that allows them to remove these errors.

Differential GPS counteracts most of these errors with the exception of multipath and receiver errors. Table 4.1 summarizes GPS error sources, while Table 4.2 summarizes GPS accuracy, with and without differential correction.

Table 4.1 Source and magnitude of GPS receiver error

Per Satellite Accuracy	**Standard GPS (in meters)**	**Differential GPS (in meters)**
Satellite Clocks	1.5	0
Orbit Errors	2.5	0
Ionosphere	5.0	0.4
Troposphere	0.5	0.2
Receiver Noise	0.3	0.3
Multipath	0.6	0.6
Selective Availability	30.0	0

Table 4.2 GPS accuracy, with and without differential correction

Typical Position Accuracy	Standard GPS (in meters)	Differential GPS (in meters)
Horizontal	50	1.3
Vertical	78	2.0
3-D	93	2.8

A differential GPS uses two receivers in order to give very accurate position measurements. One of the receivers is a normal GPS receiver that can wander around (called the “rover” receiver), while the other is stationary (called the “base” receiver). The base is located at a known location or position. This receiver compares the position measurement that it receives from the GPS satellites to its known position, determines the errors in the signal, and calculates a differential correction for the rover (see Fig. 4.4).

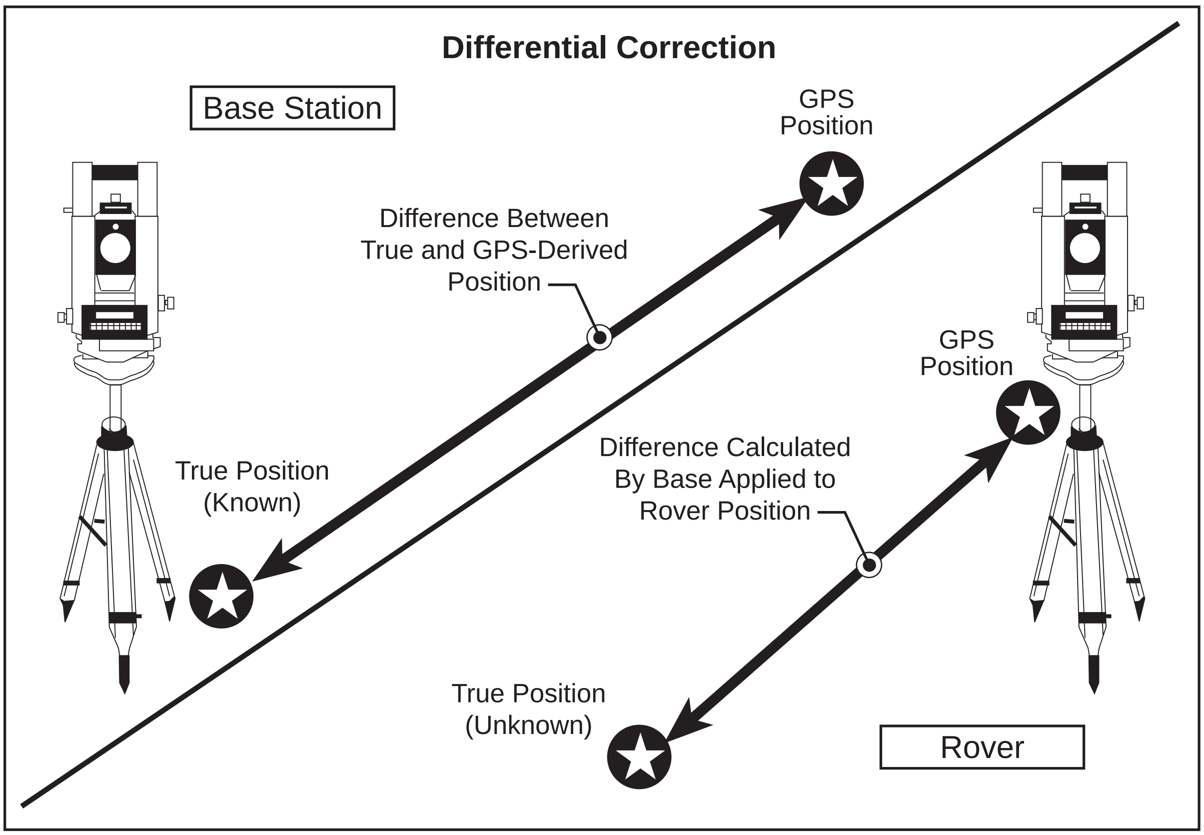

Figure 4.4 GPS differential correction concept

4.4.4. Field Test of GPS Accuracy

As mentioned above, two GPS units have been purchased for the use of the survey crew. Shown in Figure 4.5, from left to right, is the Trimble Scout GPS receiver, the Geo Explorer receiver, and the ACCQPOINT FM differential receiver. The Scout has no capability of receiving differential correction information, so it is used alone; the Explorer has a socket that can be used either to connect the FM differential receiver or to connect directly to a laptop or desktop computer. There are two ways the Explorer can be used with a computer: In the field, the laptop can collect satellite data from the GPS receiver for differential correction later, or the GPS can download its data to the computer later when the crew returns to the office. Although this mode of operation was tested, the recommended procedure is to differentially correct in real time and log the results to the survey form or store them in the GPS receiver memory.

Figure 4.5 (left to right) Trimble Scout, GeoExplorer, and Accqpoint FM Receiver to be used in 1996 condition survey

Using the two receivers in the modes described above, a field test was conducted to determine the accuracy and repeatability of the two units. The test procedure employed was a simple factorial design using two operators visiting three locations in Houston and San Antonio on two different days using both units consecutively. The primary factor to be determined was the ability of the two units to accurately mark and relocate a test section at a later time. Table 4.3 shows the results of the field experiment.

Table 4.3 Results from Scout and Explorer GPS receivers

Loc	Unit	Date	Operator	N. Latitude	W. Longitude
1	Exp	2/19	Cesar	29.60133889	98.27755833
1	Sct	2/19	Cesar	29.60196667	98.27706667
1	Exp	2/19	Robert	29.60125833	98.277625
1	Sct	2/19	Robert	29.6025	98.27618333
1	Exp	2/20	Cesar	29.601325	98.27756389
1	Sct	2/20	Cesar	29.60145	98.27743333
1	Exp	2/20	Robert	29.60131667	98.27761111
1	Sct	2/20	Robert	29.60033333	98.27663333
2	Exp	2/19	Cesar	29.59842222	98.27746389
2	Sct	2/19	Cesar	29.59875	98.27773333
2	Exp	2/19	Robert	29.59838611	98.27746389
2	Sct	2/19	Robert	29.59783333	98.27618333
2	Exp	2/20	Cesar	29.59844722	98.27744167
2	Sct	2/20	Cesar	29.59853333	98.2773
2	Exp	2/20	Robert	29.59843056	98.27748333
2	Sct	2/20	Robert	29.59633333	98.27523333
3	Exp	3/04	Robert	29.77875278	95.43127778
3	Sct	3/04	Robert	29.77876667	95.43106667
3	Exp	3/05	Robert	29.778775	95.43121667
3	Sct	3/05	Robert	29.77905	95.431

In the table, Locations 1 and 2 were selected within the San Antonio FM differential correction service area. Location 3 was in Houston. For the first two locations, two operators were used. After the data demonstrated that no operator effect was present, Location 3 was marked using just one operator. Each of the three locations was visited on two separate occasions to determine the repeatability of the measurement. The distance (error) between the two measurements was calculated according to the following formula:

$$\mathrm{COS}^{-1}[\,\mathrm{Cos}\,(a1)\,\mathrm{Cos}\,(b1)\,\mathrm{Cos}\,(a2)\,\mathrm{Cos}\,(b2) + \mathrm{Cos}\,(a1)\,\mathrm{Sin}\,(b1)\,\mathrm{Cos}\,(a2)\,\mathrm{Sin}\,(b2)$$

$$+ \mathrm{Sin}\,(a1)\,\mathrm{Sin}\,(a2)\,] / 360 * 2\,\pi * r$$

where:

a1	=	latitude of point 1,
b1	=	longitude of point 1,
a2	=	latitude of point 2,
b2	=	longitude of point 2,
p	=	3.14159, and
r	=	radius of the earth, 6,371 km, 3,956 mi, 20,889,744 ft.

Note that north and east are positive latitude and longitude, respectively, so in Texas, west longitude should be entered as negative in the above formula. Also, the above formula assumes a perfectly spherical earth, whereas it is well known that the earth bulges slightly at the equator (r = 6378 km). However, for closely spaced points (e. g., within Texas) the equation gives excellent results. Table 4.4 shows the analysis of the data for repeatability.

Table 4.4 Repeatability of the GPS receivers

Location	Scout Error (m/ft)	Explorer Error (m/ft)
1	154.5/506.9	2.6/8.5
2	116.68/382.8	3.87/12.7
3	32/105.0	6.4/21.0
Average	101/331.6	4.3/14.1

As can be seen from the table, the results for each unit were essentially as advertised. The Explorer, differentially corrected, provided a location precise to about 3 m (10 ft), regardless of the current random error contained in the satellite signals. The Scout, which is uncorrected, wanders on the path of a 100-m (328-ft) circle, as explained in the theoretical discussion above. In fact, it was unnecessary to perform the tests on different days; a delay of several hours would have produced the same results.

The conclusion from this experiment is obvious: Any operator can obtain accurate, repeatable results (to about 3-m [10-ft] precision) at any location using the differentially corrected receiver; regardless of operator, this cannot be done with the uncorrected (Scout) receiver. Relocating the pavement section to 3-m (10-ft) accuracy is more than sufficient for building a reasonable history of pavement performance, and far better than the previous system in which as many as 20% of the pavement sections are not precisely located each survey year.

4.4.5. Practical Considerations from Field Experience

At the time of this writing, the field crews had used the two GPS units in the field for several months. The following summarizes their experience:

(1) Both GPS units were reliable in the field, operating either from batteries or from the vehicle cigarette lighter jack.

(2) Both GPS receivers picked up sufficient satellite data to function statewide regardless of location.

(3) The GeoExplorer acquired the necessary number of satellites to determine location significantly faster than the older Scout.

(4) Neither GPS receiver could be used inside the car without the external antenna.

(5) The FM differential correction receiver failed after the first month of use and had to be replaced; the second unit gave no further problems.

(6) The FM receiver functioned at nearly all locations, but required a larger, external antenna when used at a distance from large metro areas.

(7) Both systems were easy to use and significantly more reproducible than the milepost/odometer location method currently used.

4.5. SUMMARY

Relocating the survey sections accurately has been problematic since the inception of the RP database; prior to this study, no system had been proposed to improve section location. Using mileposts or milepoint markers in conjunction with the vehicle odometer was always imprecise and caused additional confusion whenever the mileposts were changed. The use of paint markings, although very precise, was unreliable from year to year owing to covering by overlays and simple eradication over time.

Preliminary testing in the field indicates that GPS section location is simple, cost effective, and repeatable over time for the foreseeable future. The GPS hardware without FM differential correction locates the sections theoretically to within a three-dimensional precision of about 91 m (300 ft); in practice, since the rater knows the location must be on the linear roadway (not above, below, or to the side), the effective accuracy of the uncorrected system is about ±30.5 m (100 ft). The theoretical precision of the FM-corrected system is about 3 m (10 ft), which was verified by testing and preliminary use in the field. Although a more precise (1 m, or 3.28 ft) differential correction signal is available for additional cost, the inherent limitations of the handheld receiver (internal noise, multipath reception, etc.) as shown in Table 4.1 are the limiting factors at this level and essentially restrict the accuracy of the system to the 3-m (10-ft) level.

The only remaining area of concern is continued availability of the FM correction signal. Several companies provide this signal on an annual lease basis. Like cellular phones, the coverage area varies, since each service provider maintains broadcast facilities in different cities, with a typical reception radius of about 96.5 km to 144.8 km (60 to 90 miles). Because the demand for this service is very high, it appears that the service will always be available from someone in the near future. Our current coverage area, provided by DCI, is shown in Figure 4.6. More than 80% of the RP database sections are within one or more of the coverage areas.

At some point, a satellite correction broadcast, which has no gaps in coverage area and is available currently for about $4,000/year, will become more affordable and presumably will replace the FM correction scheme entirely. It is also possible that the military will decide to discontinue selective availability, automatically upgrading handheld GPS units to the 3-m (10-ft) range with no external correction needed.

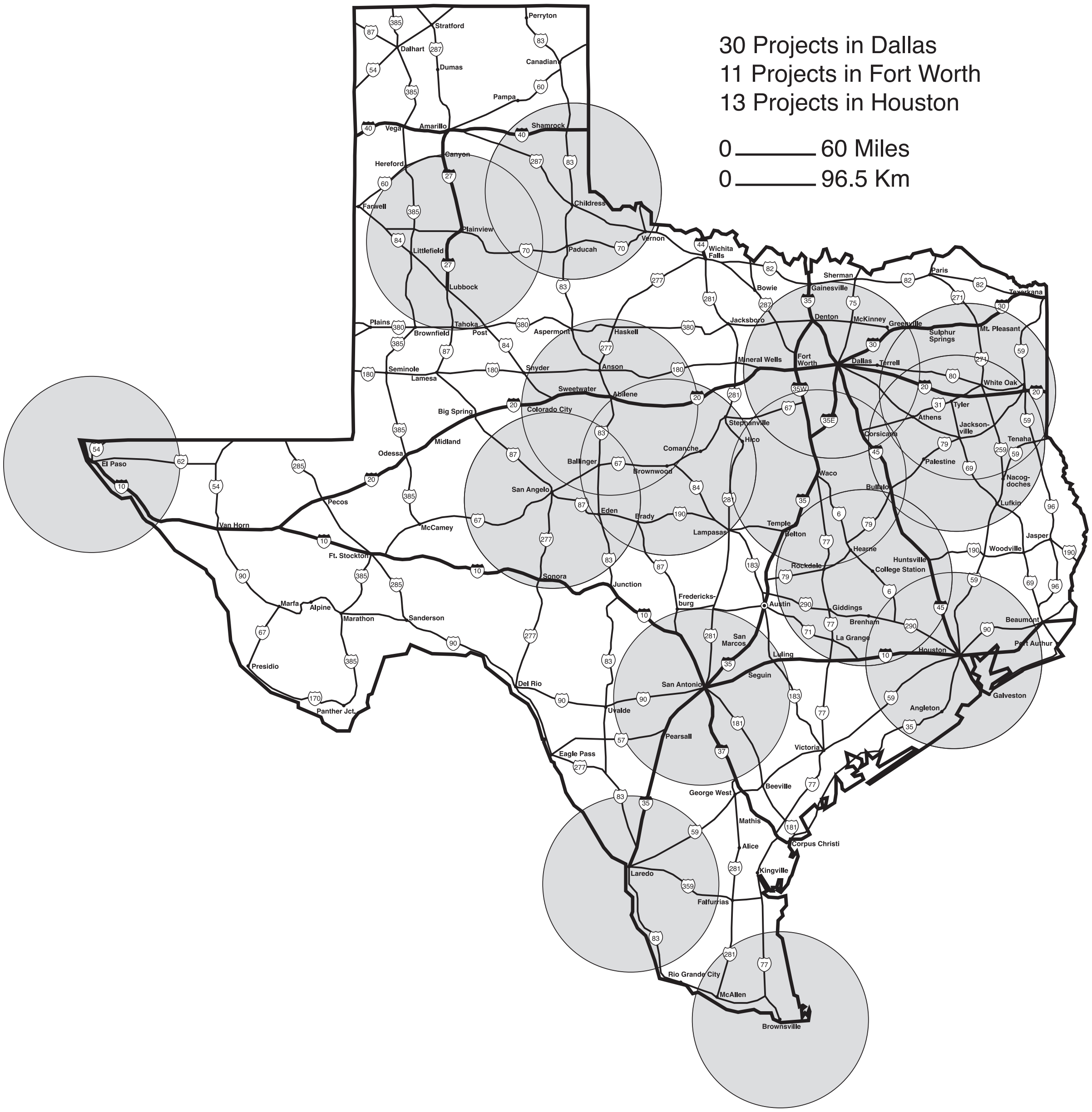

Figure 4.6 Current coverage area for FM differential correction

CHAPTER 5. SUMMARY AND RECOMMENDATIONS

5.1. SUMMARY

The previous chapters have examined the history and content of the rigid pavement (RP) database, with the intent of identifying areas for improvement in the following areas.

5.1.1. Understanding the Existing Historical Data

The RP database already contains a large amount of information dating back to 1974; these data constitute an invaluable historical record of pavement performance over a twenty-three-year period. However, the types of data collected and the collection procedures have changed markedly since 1974. Using the database effectively requires an understanding of the procedures and definitions used during each survey period.

5.1.2. Keeping the Database Useful

A necessary first step to updating the RP database is to examine the past and present uses of the database, and then to look toward the future. The current and expected use for the database in the near future is design oriented. To stay current, the database demographics must change to reflect current design practice elements, such as thicker pavements and new steel designs. The current database contains primarily 20.3-cm (8-in.) sections with a single reinforcement layer. Thicker pavements with double-matted steel must be identified and monitored in the database to keep it relevant.

The database must become more compatible with the PMIS database so that performance models developed using the RP database can be implemented in the PMIS. Distress definitions must be standardized between the two databases, and the RP database must include, as a minimum subset, the independent predictor variables available to the PMIS so that useful models can be developed. Additional independent variables found to be significant in the database can then serve as a basis for recommending additional data collection by the PMIS in the future.

Finally, the data collected for the RP database must reflect and support the areas investigated in contemporary studies. For example, several studies are examining the effect of evaporation rate and amount on plastic shrinkage, cracking, and spalling. The data collected for the RP database should now include spalling and evaporation rate to generate a historical perspective on this theory.

5.1.3. Improving Section Identification

Chapter 4 explains the need for better section identification. More than five years may pass between surveys on a given pavement. In that time, mileposts may change and paint markers are likely to be covered or eradicated. Precise relocation of the survey sections each survey period is essential for constructing an accurate distress history for each section. Previous studies have concluded that erection/maintenance of permanent markers (e.g., SHRP signs) for the RP database sections is not economically feasible.

To solve this problem, an investigation of currently available GPS units was conducted. Two inexpensive, handheld systems were tested, with the resulting determination that an FM differentially corrected GPS unit could reliably locate field sections to a precision of 3 m (10 ft), solving this recurring problem for the foreseeable future. The latitude and longitude coordinates recorded by the GPS unit are also easily translatable to any Geographical Information System (GIS) that could then be used to map the sections. The SAS under which the RP database is currently maintained contains a rudimentary GIS.

5.2. RECOMMENDATIONS

Considering all the previous discussion, the following recommendations are suggested for updating the RP database; these recommendations should be introduced in the 1996-1997 collection period and then examined/revised at the end of that period:

(1) Obtain overlay dates since 1987 from district offices, then

survey all asphalt-overlaid CRCP using new survey form (see appendix)

(2) Prioritize the survey of CRCP thicker than 20.3 cm (8 in.)

(3) Identify and collect data on new CRCP, preferably those used in connection with the development of the QC/QA specification for PCC

(4) Continue to incorporate survey data from other TxDOT projects studying CRCP

(5) Prioritize adding RP sections with new design or construction elements

(6) Continue to update climatic data (evaporation, temperature, etc.; see Chapter 3) from NOAA sources

(7) Update traffic data since 1987 using AADT maps and WIM data

(8) Locate any existing drainage improvements during district visits

(9) Continue to collect and verify GPS data to improve section location

(10) Continue to provide data to other research studies as needed

Most of these recommendations were discussed in detail in Chapter 3. Chapter 4 addressed the need for more precise section location and acquisition of the GPS. It is expected that all of the above recommendations will be implemented for the 1996 condition survey. The results of the field survey will be documented in the next report for this project, which, according to agreement with the TxDOT project director, will also be the final report detailing any modeling and data analysis performed.

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APPENDIX:

REVISED RATING FORMS

CTR No.							Dir.	

North - Latitude								
		°		’		.		”

West - Longitude								
		°		’		.		”

Date					

Surveyors					

CRCP Distress Survey (Overlaid)

Reference Marker ______ ______ Start Point					End Point					Cracking		Rutting**		Number of AC Patches (sq ft)			Slabs w/Longitudinal Cracks	No. of Punchouts		Transverse Cracks	
										Alligator Cracking**	Block Cracking*	Shallow (≥0.5" - 1.0")	Deep (≥1.0" - 3.0")	1 - 50	51 - 150	>150		M	S	No. of Cracks	Crack spacing (accumulative distance from the starting point to each crack) for the first 200 ft only. (Indicate patch location with a circle) (Indicate joints with a circle and letter J)
		0	•	0	2	0	0	•	0												
2	0	0	•	0	4	0	0	•	0												
4	0	0	•	0	6	0	0	•	0												
6	0	0	•	0	8	0	0	•	0												
8	0	0	•	0	E	N	D														

*Percent of Rated Lanes Total Surface Area

**Percent of Total Wheel Path Area

Condition of Shoulders ______________________________

General Comments ______________________________

CTR No.							Dir.	

North - Latitude								
		°		’		.		”

West - Longitude								
		°		’		.		”

Date					

Surveyors					

CRCP Performance Survey (Nonoverlaid)

Reference Marker					Start Point (ft)					Punchouts (ft)		Patches AC (ft²) PCC						Transverse Cracks	
										M	S	1 - 50	51 - 150	>150	1 - 50	51 - 150	>150	No. of Cracks	Crack spacing (accumulative distance from the starting point to each crack) for the first 200 ft only.
			•				0	•	0										
			•		2	0	0	•	0										
			•		4	0	0	•	0										
			•		6	0	0	•	0										
			•		8	0	0	•	0										

M – Minor
S – Service

AC – Asphalt Concrete
PCC – Portland Cement Concrete

Condition of Shoulders ____________________

General Comments ____________________