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16. Abstract

This project has demonstrated that it is possible to track the network-level performance of surface mixtures constructed in Texas. A procedure is outlined in the report to accomplish this and involves firstly identifying a project's extents in terms of Texas Reference Marker (TRM) information. A web-based tool was developed to allow TRM information to be derived for SiteManager projects constructed in Texas. This involves locating the beginning and ending points of a project as described in TxDOT SiteManager and/or Design and Construction Information System (DCIS) databases and interpolating the TRM information from a geographical database containing longitude and latitude coordinates of TRMs in Texas. The web-based tool provides street, topographical and satellite aerial maps to assist with the identification of the project extents. Once TRMs for a project are defined, network level performance indices and measures may be extracted for the project from the TxDOT Performance Management Information System (PMIS) database. The procedure as outlined is subject to certain constraints that are discussed in the report, most notably the assumption that the performance information as reported is for the asphalt mixture on the surface of the road being queried, which is not necessarily the case.

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Developing a Sustainable Flexible Pavement Database in Texas

André de Fortier Smit
Jorge A. Prozzi

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Products

Two products were completed as part of this project. First a web-based software application and second a user's manual for the software application. Both products have been delivered at TxDOT on CD but are also available from the following internet address: http://pavements.ce.utexas.edu/TxDB/TxDB.html

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Chapter 1. Introduction

1.1 Background

The Texas Department of Transportation (TxDOT) specifies a large number of different hot-mix asphalt (HMA) mixtures for use as base and surfacing layers on pavement structures. Table 1.1 shows a breakdown of the HMA mixtures currently used in Texas that were addressed as part of the project. The different mixtures are used for different applications and while these vary in cost, the mixtures will also perform differently depending on the traffic and environmental conditions to which they are subjected to. This array of mixtures presents asphalt mixture designers with the challenge of selecting the right mix for the right job. Furthermore, the cost of paving a mixture must be justified in terms of actual performance. While pavement engineers have an intuitive opinion regarding the relative performances of different asphalt mixtures, no quantitative evidence is readily available to prioritize one mixture over another. Addressing this shortcoming was a focus of the research.

Table 1.1: HMA used in Texas

Mix	TxDOT Specification
Dense-graded • Type A*,B*,C,D & F	Item 341
Porous Friction Course (PFC) • With PG76 and TR binders	Item 342
Superpave (SP) • Type A*,B*,C,D & F Coarse Matrix High Binder (CMHB) • Type C & F	Item 344
Stone-Matrix Asphalt (SMA) • Type C & F	Item 346

*Base course mixtures were included in the research for SiteManager reporting

Pavement Management Information Systems (PMIS) are based on procedures to track the performance of asphalt and concrete pavements over time. This allows the ability to determine where and why specific pavements are performing well and provides important life cycle information. A system that facilitates the evaluation of the cost and performance information of asphalt mixtures provides pavement engineers with a tool to calculate the cost-benefit ratio of asphalt pavements. This was the impetus driving the "PathFinder" study, a Federal Highway Administration (FHWA) initiative that made use of PMIS data to monitor the performance of Superpave mixtures constructed in the US (Hudson et al., 2002). One of the authors, Dr. Smit, was involved with this project through an interagency-contract (IAC) with TxDOT that specifically addressed the performance of Superpave mixes in Texas, the majority of which were constructed in the Abilene district at the time. An unpublished report detailing these efforts was completed and submitted to the FHWA (Smit, 2005). In this report a procedure was outlined to track the network-level performance of Superpave mixes in Texas using TxDOT databases.

TxDOT has databases and infrastructure in place to evaluate the cost and performance of asphalt mixtures. Generally lacking is the ability to quickly assimilate this information to derive cost-benefit ratios. Historically, the letting and performance information of asphalt mixtures used in Texas have been archived and processed separately. Project letting information of asphalt mixtures has been collected since about 1984 as part of the TxDOT Design and Construction Information System (DCIS). Performance related data has been collected from about 1985 as part of the TxDOT Pavement Management Information System (PMIS). DCIS databases include lettings and budget-related information such as quantities and pricing of asphalt concrete pavement projects. The PMIS database contains performance-related data including summary information in the form of indexes and field performance data such as rutting, cracking, and roughness measurements for all TxDOT roads. The FHWA report (Smit, 2005) outlined developments undertaken to relate DCIS and PMIS data towards tracking the performance of Superpave mixtures in Texas. To provide additional background information for the current project, these database systems and the development undertaken as part of the PathFinder study are briefly discussed next.

1.1.2 PathFinder's DCIS-PMIS Implementation

The DCIS database can be used to locate where specific asphalt mixtures are paved in Texas. The primary key in the DCIS database is the Control Section Job (CSJ) field. This is a unique identifier defining a lettings contract. A lettings contract may include construction or maintenance jobs on a number of different roads or highways, although in most cases it is restricted to particular counties within Texas districts. The CSJ of a project provides a means to determine which materials were let or used on the project. It is important to note that the materials, and in particular, the asphalt mixtures used during construction may vary for the different sections on the same job. In general, however, a single mixture is used for a particular project. A DCIS record will identify the district, the county, and the highway on which work is being (or has been) let. DCIS includes fields to identify the geographical location of sections being constructed including the beginning and endings stations as well as the project midpoint longitude and latitude coordinates. Unfortunately, these fields are not mandatory inputs and are generally not maintained. This is a major drawback of using the DCIS database to identify the specific locations of asphalt paving projects. This information can, however, be obtained from other reference sources at the district level, e.g., project design documents. It should be emphasized, however, that this shortcoming has been addressed by TxDOT and many of the post 2004 projects now include TRM information that can be used to geographically locate TxDOT projects.

Primary keys in the PMIS database are the signed highway and reference marker fields. These identify the geographical location at which performance measurements are taken. Therefore, although there are related fields in both the DCIS and PMIS databases, there is not a single field that directly relates a record in DCIS with one in PMIS. This is partly because of the different database structures that were established to serve entirely different purposes. A project listed in DCIS may include the construction of a highway in Texas, the performance of which is subsequently monitored on a yearly basis and recorded as part of PMIS. In order to link DCIS and PMIS records it was necessary to first establish reference markers for the projects listed in DCIS. This was the single obstacle impeding the integration of DCIS and PMIS. Reference markers for constructed (or rehabilitated) highways may be determined indirectly if the mile points of these projects are available. This information may be acquired from district or area engineers responsible for the construction of these projects. In fact, this was how the geographical locations for the Superpave projects were obtained in the PathFinder study. Once the relevant records in the DCIS database have been populated with reference markers the DCIS and PMIS information may be linked directly. Reference markers allow the differentiation of sections of highways. Projects on these highways may be traced using the DCIS database that may provide asphalt mixture design information (mix, binder and modifier type) as well as information pertaining to construction costs. This information can then be related to the performance information collected from the PMIS database.

The approach as outlined above provided the motivation to expand on and apply the database and software developed under the FHWA Pathfinder study towards tracking and analyzing the performance of typical hot-mix asphalt (HMA) mixes used by TxDOT, not only Superpave. This TxDOT research project was initiated for this purpose.

1.2 Project Objectives and Scope

While the previous developments had established a link between DCIS and PMIS data, this link only accounted for a limited number of projects for which TRM information was available in the DCIS projects database (at the time this was less than 10 percent of the projects). The first objective of the project was, therefore, to upgrade and improve the link between DCIS and PMIS to allow a network-level performance assessment of HMA mixtures in Texas. As mentioned, TxDOT uses a variety of different asphalt mixes for different roadway applications. New asphalt mixes are introduced from time to time as these are developed. To narrow the scope of the research it was decided to focus the assessments on HMA mixtures as listed in Table 1.1, primarily surface mixtures that could be related to PMIS surface-related performance measurements. The primary objective of the project was, therefore, to develop a system to track the network-level performance of these HMA mixtures. It was further required, as part of the project, to implement this system within a geographical information system (GIS) web-based application. This would allow the representation of the geographical location of HMA projects being tracked from a graphical user interface (GUI) accessible to TxDOT personnel over the internet.

A project modification in 2006 expanded the scope of the research to include SiteManager data. SiteManager is a relatively new database system used by TxDOT to record project design and construction information. SiteManager was first introduced in 2004 and has been used since then to record all construction projects managed by TxDOT. The modification to the current research called for the inclusion of SiteManager projects and the reporting of SiteManager design and construction information within the web-based framework. In this regard SiteManager served to replace DCIS and the objective of the project was revised to establish the link between SiteManager and PMIS with the goal of tracking the performance of SiteManager HMA projects. In addition to tracking the performance of HMA projects, the scope of the project was further expanded to include reporting of SiteManager design and construction information for selected SiteManager projects.

Another important aspect to be addressed by the project was the comparison of the relative performance of different asphalt mixtures at a network level on similar structures under similar traffic and climatic conditions. The ability to compare different projects would provide asphalt mixture designers, as well as pavement engineers, a tool to assess the performance of different alternatives. The fact that this is a network-level comparison should be emphasized to differentiate from other concurrent efforts to monitor pavement performance at a project-level. While network level performance comparisons are not as accurate, they are more robust and general because they are based on tens of thousands of pieces of information.

During the initial application of the software developed as part of the project, it became apparent that the statistical analyses procedures provided a powerful tool to compare the relative performance of different HMA mixtures. At the time, the statistical analyses were done on data extracted from the PMIS database for selected projects being tracked. The researchers were requested to implement the statistical analysis procedures within the software package to allow real-time "on-the-fly" analysis of HMA performance. This request was implemented, as is discussed later in the report.

1.3 Report Outline

The report documents the database and the software developments carried out to establish the GIS web-based application. Steps necessary to implement the developed system within the TxDOT networking system are outlined. Various functions and tools developed within the application are then discussed. These include (i) functions to input SiteManager projects, (ii) procedures to filter and compare these projects, (iii) functions to analyze project performance trends, and finally (iv) an analysis procedure to statistically investigate the influence of various factors, including asphalt mixture type, on network level performance. A chapter is included in the report that outlines the statistical procedure applied and analyses performed to investigate the relative performance of selected asphalt mixtures. This procedure was implemented within the web-based application to allow similar real-time analyses of SiteManager projects included in the project. Based on the analyses of HMA performance, conclusions are drawn regarding the relative performance of different HMA mixtures within Texas and recommendations are made to expand the application of the software and database developments undertaken as part of the project.

Chapter 2. Database Application

This chapter outlines application of TxDOT databases as part of the project. No databases were developed as part of the research; instead the application developed makes use of existing TxDOT databases. These include DCIS, PMIS, SiteManager, and a Texas Reference Marker (TRM) database provided to the researchers by Michael Chamberlain of TxDOT that provides longitude and latitude coordinates of TRMs in Texas. This latter database, the TRMGIS database was instrumental in establishing the link between the SiteManager and PMIS databases. What follows is a brief overview of the application of these different TxDOT databases.

2.1 DCIS Database

The Design and Construction Information System (DCIS) database was discussed in the introduction to this report. Selected tables from this database were used exclusively during the initial development in the PathFinder project. Although the use of this database was phased out later in the research, a brief discussion of the database tables is relevant for an understanding of the development of the application. The relevant DCIS tables used include:

- Bid
- Project
- Proposal
- Item List
- Districts and County

The Bid table (Table 2.2) contains quantity and pricing information for the different bid items selected for TxDOT projects. The structure of this data table is as follows:

Table 2.2: DCIS Bid Table

Field	Format	Description
CONTID	varchar(15)	CSJ or project number
VENDOR	varchar(14)	Vendor Number
ITEM	varchar(13)	TxDOT specification number
BTUPRICE	decimal(13,5)	Pricing per unit quantity
BTOQTY	decimal(12,3)	Unit quantity

This listing shows the data field, the data format specifier and a description of the table field. The CONTID defines the CSJ or project number and is the principal key used to link the other database tables in the DCIS. It should be noted that the Bid table in the mainframe DCIS includes records for all tendered projects. It is necessary therefore for the DCIS database maintainer to filter out and only record those VENDORs that were contracted for the project.

The Project table (Table 2.3) includes project specific information indicating location and date of construction, etc. The following is a listing of relevant data fields:

Table 2.3: DCIS Project Table

Field	Format	Description
CONTID	varchar(15)	CSJ or project number
PJDESC1	varchar(60)	Project description
ISPECYR	varchar(2)	Specification year
COUNTY	varchar(4)	Project county number
PJDISTR	varchar(5)	Project district number
PJROADNM	varchar(60)	Road (route) name
PJBTERMI	varchar(10)	Beginning termini
PJETERMI	varchar(10)	Ending termini
PJBSTATN	varchar(20)	Beginning station
PJESTATN	varchar(20)	Ending station
PJLENGTH	decimal(9,4)	Project length
PJXCOORD	int	Longitude of midpoint
PJYCOORD	int	Latitude of midpoint

As shown above, the Project table includes fields to identify the location and extent of a project such as PJBTERMI, PJETERMI, PJBSTATN, PJESTATN, PJXCOORD and PJYCOORD. It should be noted that the input of these fields is not mandatory and unfortunately these are sparsely populated, particularly for projects prior to 2004. The researchers have noted, however, that since 2004 these fields are increasingly being populated. This is a positive development that simplifies the identification of project extents.

The ISPECYR field indicates the TxDOT specification book year. The ISPECYR field is important as ITEM numbers listed in the Bid table (shown in Table 2.2) are not necessarily the same for different specification years. The ISPECYR field also indirectly indicates the unit system applied. In the 1995 specification book only metric units were applied. Quantities and prices therefore need to be converted for unit consistency. The project length field (PJLENGTH) was particularly useful in identifying project extents as is discussed later in the report.

The Proposal table (Table 2.4) provides information for all TxDOT proposals, which (as for the Bid Table) needs to be filtered for the contracted VENDOR. The following is a listing of the relevant fields:

Table 2.4: DCIS Proposal Table

Field	Format	Description
CONTID	varchar(15)	CSJ or project number
ISPECYR	varchar(2)	Specification year
CNDISTR	varchar(5)	Primary district
COUNTY	varchar(4)	County 1,2,3 & 4
CNRDSYS	varchar(4)	Road system
CNROUTE	varchar(20)	Route
CNDTLET	Date	Letting date
CNDTSTRT	Date	Estimated starting date
CNDTCPE	Date	Estimated completion date
VENDOR	varchar(14)	Contracted vendor
UNITSYS	varchar(4)	Measurements system (English or metric)

The Proposal table includes the letting date as well as estimated starting and completion dates for a project. These dates were initially used to establish a datum from which to start tracking the performance of a HMA project as is discussed later in the report. These dates are linked to the Bid table data fields through CONTID and to the Project table fields through CONTID, ISPECYR, and route. The Proposal table can include up to four counties in which work on a project is done, all falling under a principal district. The district and county fields shown in the Proposal table are numerical indicating the district numbers (1-25) and the respective county numbers (1-254). The textual names of districts and counties were obtained by cross linking these to District and County tables, which provided a listing of the textual names and corresponding numbers.

The Item List table (Table 2.5) provides a description (IDESCR) for all TxDOT items (ITEM) let. The relevant fields in this database table include:

Table 2.5: DCIS Item List Table

Field	Format	Description
ITEM	varchar(13)	Item number
ISPECYR	varchar(2)	Specification year
IDESCR	varchar(40)	Item description
IUNITS	varchar(4)	Quantity unit

The IUNITS field in the Item List table is used for unit conversion calculations between English and metric unit systems. In the first phase of the project, the ITEM number and the description field in the Item List table were used to determine the type of asphalt mixture used on a project. The ITEM numbers indicate the specification item for asphalt mixtures (340, 341, 342, 344, and 346) and provided a link to the other tables in the DCIS. The item description

(IDESCR) was used to track mixtures that did not have a specification item number. For example, Superpave mixtures were identified by querying the Item List table with the keyword “SUPERPAVE” which in most cases provided a listing of all Superpave related ITEM numbers. This approach proved to be ineffective as not all asphalt mixture related items could be tracked. Superpave mixtures often contained the “SUPERPAVE” keyword in the description but it was sometimes misspelled or simply termed “SP” or “SPHMA”. Furthermore, prior to the inclusion of Superpave in the 2004 TxDOT specification book, most of the Superpave projects were let under Special Specifications. To overcome this problem it was therefore necessary to include a Specification Item table that would provide a listing of HMA projects that did not have an ITEM number or were let under special provisions. This significantly complicated the tracking of HMA items and was one of the primary reasons for using the SiteManager database in lieu of DCIS. The use of SiteManager eliminated the problem of identifying the HMA mixtures used on a TxDOT project as is explained in more detail later in the report.

2.2 PMIS Database

The TxDOT Pavement Management Information System (PMIS) database was briefly discussed in the introduction to this report. Two tables from the TxDOT PMIS were used:

- PMIS DATA COLLECTION SECTION
- PMIS CONDITION SUMMARY

2.2.1 PMIS Data Collection Section Table

The collection section table consists of 39 different fields detailing specific information relating to sections on which performance information, as reported in the condition summary table, was monitored. This database table includes the fiscal year in which the measurements were taken, the district, county, and route information, as well as the beginning and ending TRMs of the section monitored. This allows a direct link with the condition summary table. Other relevant fields included in the table that could be reported as part of mixture performance monitoring, particularly for comparing the performance of different sections, are discussed briefly:

18 kip Traffic: This represents the current 18 kip ESAL value obtained from the TxDOT TRM database for the data collection section. There is one 18 kip ESAL for each 18,000 pound equivalent traffic load projected over a twenty-year period. Only the highest 18 kip for any portion of the segment is used—18 kip is analogous to the working load on the highway. These values are stored in thousands, so for example, 5 million cumulative 18-kip ESALs is stored in the database as 5000.

AADT Traffic: This represents the annual-average-daily-traffic and is the published average daily estimate of vehicles for all lanes of traffic on a particular highway (single direction for mainlanes, possibly both directions for frontage roads) over the length of a traffic section. This figure includes various “adjustments” such as axle factors, seasonal variations, group factors, dummy figures, etc. used to help track traffic trends even though it is not flagged as an “adjusted” AADT. The highest ADT for any portion of the data collection section is used. ADT is accessed once a year at the beginning of the data collection cycle. It remains unchanged to insure reports produce consistent results. AADT values in PMIS are stored by roadbed.

Maintenance cost: The cost of maintaining the main travel lanes *during* the year of data collection. This is calculated from maintenance costs in the TxDOT Maintenance Management Information System (MMIS).

Pavement type: This indicates the predominant travel lane pavement type during the data collection year of the data collection section. PMIS lists the following pavement types:

1. Continuously Reinforced Concrete (CRCP)
2. Jointed Reinforced Concrete (JRCP)
3. Jointed Plain Concrete (JPCP)
4. Thick Asphaltic Concrete (Over 5.5")
5. Medium Thickness Asphaltic Concrete (2.5 - 5.5")
6. Thin Asphaltic Concrete (Under 2.5")
7. Composite (Asphalt Surfaced Concrete)
8. Widened Composite Pavement
9. Overlaid and Widened Asphaltic Concrete Pavement
10. Surface Treatment Pavement (Or Seal Coat)

For the current project only asphalt concrete related projects are considered, i.e., 4, 5, 6, and 9 as listed above. This distinction was made to ensure that seal coats and other surface types are not considered in the performance analyses described later in the report.

2.2.2 PMIS Condition Summary Table

The Condition Summary table consists of 47 different fields comprising performance summary data. A brief explanation of the different fields is given, based largely on comments from the PMIS data dictionary report as developed by TxDOT:

Fiscal year: This field identifies in which year the performance measurements (pavement distress, ride, skid, and structural data) were taken. This year is designated by the design division of TxDOT and is the fiscal year in which the data collection cycle begins. A collection cycle is usually from September through January for ride and visual distress.

Signed Highway Roadbed ID: This field includes the highway system, the highway number, and the roadbed identification number. The highway system is a code designated by the highway commission to describe the signing of a highway section. It consists of two characters, the description of which is given in Table 2.6. The highway number is a four character number attached to the highway system. For non-state maintained connectors of highway routes, the highway number for the connecting route will be the same as that of the state maintained route that it connects. The roadbed ID is a code identifying separate roadbeds that constitute a highway section as shown in Table 2.7.

Table 2.6: PMIS Highway Systems

Highway System	**Description**
IH	Interstate Highway
US	US Highway
UA	US Alternate
UP	US Highway Spur
SH	State Highway
SA	State Highway Alternate
SL	State Highway Loop
SS	State Highway Spur
BI	Off Interstate Business Route
BU	Off US Highway Business Route
BS	Off State Highway Business Route
BF	Off farm or Ranch to Market Road Business Route
FM	Farm to Market Road
RM	Ranch to Market Road
RR	Ranch Road
PR	Park Road
RE	Recreation Road
FS	Farm to Market Road Spur
RS	Ranch to Market Road Spur
RU	Ranch Road Spur
RP	Recreation Road Spur
PA	Principal Arterial Street System (PASS)
MH	Metropolitan Highway

Table 2.7: PMIS Roadbed ID

Roadbed ID	Description
K	Single mainlane road
A	Right frontage/service road
R	Right main lane road
X	Left frontage/service road
L	Left main lane road

Beginning and Ending Reference Marker Numbers: A reference marker number is assigned to a physical marker on the highway that identifies the location on a highway. Physical markers are numbered from state-line to state-line and from westernmost or northernmost point of the highway origin, i.e., south to north for interstate highway post numbering. TxDOT has issued a handbook that details the TRM system as applied in Texas. Since TRM locations for a route may change over time, for accuracy, TRM information should be maintained by date. For the current study, the researchers made use of TRM information provided in 2007.

Beginning and Ending Reference Marker Distance: This specifies the distance from a reference marker in tenths of a mile. This field may be negative indicating an opposite direction.

Distress Score: This describes the overall amount of surface distress (such as cracking, patching, rutting, etc.) on the data collection section. Distress score is a product calculated from utility values for each distress evaluated on a pavement type. The utility value represents the value of service provided by the damaged pavement from 0 (worst) to 1 (best). This allows different pavement types to be compared.

Condition Score: This describes the overall condition of the data collection section in terms of surface distress and ride quality. Condition score resembles the average person's perception of pavement quality - what you see (distress) and what you feel (ride). Values range from 1 (worst) to 100 (best).

Ride Score: This describes the overall ride quality of the data collection section. Valid values range from 0.1 (roughest) to 5.0 (smoothest). Ride-score is the length-weighted average of the raw serviceability index (SI) values measured in the data collection section.

Left IRI: This is the average of the International Roughness Index (IRI) determined in the left hand wheelpath for all IRI data collected in the data collection section. The IRI measures the pavement's longitudinal profile.

Right IRI: As above but for the right hand wheelpath.

Shallow Rut: This indicates the average percentage of shallow rutting for all data collected in the data collection section. A rut is a surface depression in a wheelpath. Rutting in the rated lane may be observed in one or both of the wheelpaths. Rutting is caused by consolidation or lateral movement of the pavement and indicates structural failure of the surface or sub-surface pavement layers. Shallow rutting is defined as permanent deformation in the range from 0.24 – 0.49 inches.

Deep Rut: This indicates the average percentage of deep rutting for all data measured by automated equipment (rutbar) in the data collection section. Deep rutting is defined as permanent deformation in the range from 0.50 – 0.99 inches.

Severe Rut: As above but defined as permanent deformation in the range from 1.00-1.99 inches.

Block Cracking: The percentage of lane area with block cracking in the measured lane of the data collection section. Block cracking consists of interconnecting cracks that divide the pavement surface into approximate rectangular pieces, varying in size from 1 foot by 1 foot up to 10 feet by 10 feet. Although similar in appearance to alligator cracking, block cracks are much larger. Block cracking is not load-associated. Instead, it is commonly caused by shrinkage of the asphalt concrete or by shrinkage of cement—or lime-stabilized based courses.

Alligator Cracking: The percentage of wheelpath length with alligator cracking in the measured lane of the data collection section. Alligator cracking consists of interconnecting cracks which form small irregularly shaped blocks which resemble the patterns found on an alligator's skin. Blocks formed by alligator cracks are less than 1 foot by 1 foot (larger blocks should be rated as block cracking). Alligator cracks are formed whenever the pavement surface is repeatedly flexed under traffic loads. As a result, alligator cracking may indicate improper design, weak structural layers, or heavily-loaded vehicles.

Longitudinal Cracking: This is the average length, in feet per station, with longitudinal cracking in the measured lane of the data collection section. A "station" is a construction station (length = 100 feet). Longitudinal cracking consists of cracks or breaks which run approximately parallel to the pavement centerline. Edge cracks, joint or slab cracks, and reflective cracking on composite pavement may all be rated as longitudinal cracking. Differential movement beneath the surface is the primary cause of longitudinal cracking.

Patching: This is the percentage of lane area with patching in the rated lane of the data collection section. Patches are repairs made to pavement distress. The presence of patches indicates prior maintenance activity, and is used as a general measure of maintenance cost.

Transverse Cracks: This is the number of transverse cracks per station in the measured lane of the data collection section. A "station" is a construction station (length = 100 feet). Transverse cracks are measured as the number of equivalent full lane width cracks. For example, two cracks that each go halfway across the lane will be measured as one transverse crack. Transverse cracking consists of cracks or breaks which travel at right angles to the pavement centerline. Joint cracks and reflective cracks may also be measured as transverse cracking. Transverse cracks are usually caused by differential movement beneath the pavement surface but may also be caused by surface shrinkage due to extreme temperature variations.

ACP Failures: This indicates the number of visually observed failures in the rated lane of the data collection section. A failure is a localized section of pavement where the surface has been severely eroded, badly cracked, or depressed. Failures are important to rate because they identify specific structural deficiencies which may pose safety hazards. Rutting failure is defined as deformations in the range from 2.00 – 3.00 inches.

Visual Lane Code: This code identifies the lane of the data collection section for which the visual distress data was collected. Rated lanes are numbered as shown in Figure 2.1 and Figure 2.2 for undivided and divided roadbeds respectively. Lanes are numbered 1- 5 in the direction of increasing TRM and 6 - 0 in the direction of decreasing TRM.

The visual lane on which PMIS distress measurements were done is an important factor that should be carefully considered. As part of this project it was impossible to exactly identify the lane on which an asphalt mixture was paved. This information is not available from either the DCIS or SiteManager databases. The description fields in these databases may, however, indicate whether the job was done on the mainlanes or frontage roads of a particular route. It was assumed, therefore, for the performance analyses procedures that the entire roadway (either mainlane or frontage road) in both directions was paved with a particular mixture when constructed. This may not necessarily be the case, especially for divided mainlanes, but may be reasonable for single-lane roadways and undivided mainlanes.

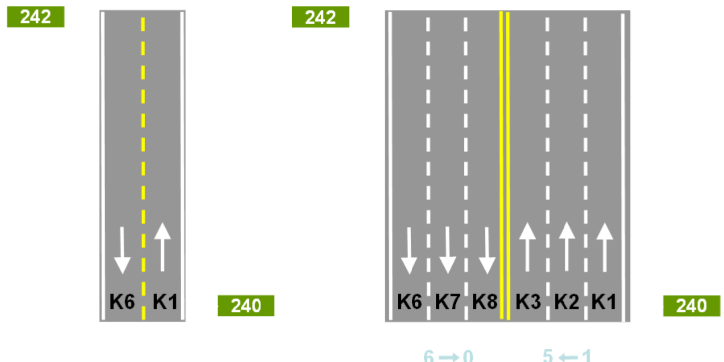


Figure 2.1: Undivided Lane Identification

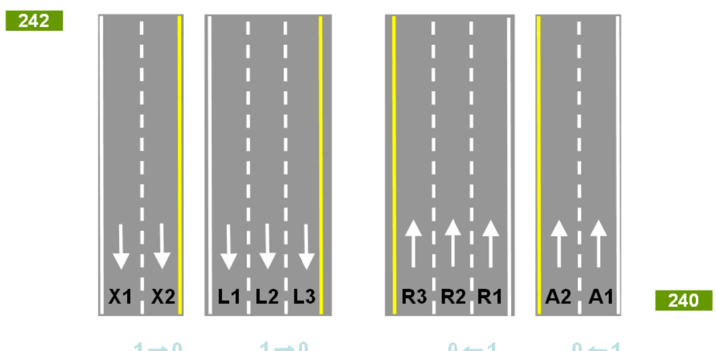


Figure 2.2: Divided Lane Identification

2.3 SiteManager Database

The TxDOT SiteManager database includes design and construction QC/QA records for HMA projects in Texas. The construction records from contractor quality control and TxDOT quality assurance are input for the four sublots that make up a lot during construction. A lot is the quantity of HMA making up one day's production, typically about 2,000 tons.

As mentioned previously, it was decided to use SiteManager in place of DCIS to identify HMA projects in Texas. The advantage of this is that SiteManager indicates directly the HMA mixture used on a project. Furthermore, SiteManager indicates the date when each lot was placed, so the date of the final lot may be used to more accurately indicate when the project construction was completed. Typically, HMA roads are opened to the public shortly after construction.

The primary advantage of including SiteManager, however, is that design and construction records for a particular project may be reported and used in performance analyses. This opens up numerous possibilities that, although beyond the scope of the current project, may be explored in more detail now that the infrastructure to do so is in place. This system provides the possibility of comparing TxDOT and contractor test results, identifying the service life of HMA surface mixtures, and ultimately relating mixture design and construction information to network-level performance. The latter possibility could be used to develop performance-based specifications for HMA used in Texas and for refining pay-factors based on performance that could be applied during construction. The software developments in the current project provide the tools necessary to accomplish this and it is recommended that these possibilities be explored in future TxDOT projects.

The SiteManager database, in addition to the QC/QA design and construction records, includes Project and Item List tables that are very similar to the equivalent DCIS tables outlined previously. SiteManager also include a CCSJ table that allows all QC/QA data identified through a sample identification number (SMPL_ID) to be linked to a particular project number via two primary keys, i.e., the control section job (CONT_ID) and project control number (PRJ_NBR). The fields in the CCSJ table are shown in Table 2.8. While the CONT_ID and PRJ_NBR fields for a particular project may be the same, there are projects with multiple PRJ_NBR entries for a single CONT_ID. The LN_ITM_NBR indicates a unique number describing a particular item as it appears on the contract. It is possible for one project to be comprised of more than one asphalt mixture, e.g., base and surface courses, which would then each have unique line item numbers. The sample identification number (SMPL_ID) is a unique identifier for a sample collected on the project for QC/QA testing.

Table 2.8: SiteManager CCSJ Table

Field	Format	Description
CONT_ID	nvarchar(15)	Control section job number
PRJ_NBR	nvarchar(13)	Project control number
LN_ITM_NBR	nvarchar(4)	Line item number
SMPL_ID	nvarchar(18)	Sample identification number

The SiteManager QC/QA database table is a comprehensive table including the results of all laboratory and field tests done on samples collected on the project. Table 2.9 shows the relevant fields in this table, the SMPL_ID being the primary key that can be linked to the CCSJ table for project identification.

The test method (TST_METH) field indicates which method was used for testing the material. For HMA projects this indicates the QC/QA spreadsheet templates used. The QC/QA spreadsheet templates are filled out by TxDOT field personnel and contractors and record all

QC/QA data collected from laboratory and field tests. Data from these spreadsheets are later imported into the SiteManager database. As new mixtures are introduced or as specifications evolve or change, these templates are updated accordingly. The TST_METH field indicates which spreadsheet template was used to collect the QC/QA data. The sample test number (SMPL_TST_NBR) is a number that uniquely identifies the test when the same test method is performed multiple times on one sample. Thus, for multiple lots within a project, one will have different sample test numbers.

Table 2.9: SiteManager QC/QA Table

Field	Format	Description
SMPL_ID	nvarchar(18)	Sample identification number
TST_METH	nvarchar(10)	Test method applied
SMPL_TST_NBR	nvarchar(10)	Sample test number
TST_FLD_SN	decimal(5)	Test field sequence number
TST_STRG_FLD_VAL	nvarchar(255)	Test field value (string)
TST_NUMRC_FLD_VAL	nvarchar(18)	Test field value (number)

The test field sequence numbers relate to specific field numbers in the spreadsheet templates that indicate the different HMA properties being recorded. It is important to note that these field numbers are not necessarily the same for the different spreadsheet versions or test methods (TST_METH) applied even though the property being recorded may be the same. This complicates the identification of material properties in the QC/QA and requires the use of a lookup table to ensure that each property value is matched with the corresponding test method or spreadsheet template applied. The test field value is the actual test result measured for the HMA property indicated. While the QC/QA table provides for both string and numeric values, only the string value field is used. Thus, all HMA property values are input as string values in the SiteManager QC/QA table.

The SiteManager QC/QA table as it is currently being maintained has serious drawbacks. The following is a listing and brief discussion of these:

No input validation: Data is input into the SiteManager database without validation. This severely impacts confidence in the reliability of the SiteManager data. Some input fields are clearly incorrect and this data cannot be used in the analyses. Furthermore, some fields are left empty and the user is not prompted to complete these. Consequently, the lot information is lacking, which restricts the statistical analyses that can be run and the value to be gained from the data.

No input verification: The user is left to decide the format of some of the input data fields. As all inputs are stored as string fields in the database, the user can input anything and it will be accepted. For example, heights are input in metric and/or English units. Some users input the units together with the values, for example, 2.0" or 2.0 in, or 2.0 inches, etc. Unfortunately, there is no consistency with these inputs; therefore, in order to run analyses on this data, these fields must first be "cleaned" by removing the text strings.

No calculated fields: The SiteManager QC/QA table currently only includes those HMA mixture properties that were measured from laboratory or field tests. So, for example, density is not stored but the inputs required to calculate density are, such as wet, dry, and surface saturated dry (SSD) weights. While on the surface this may appear to be a good policy since the user can calculate these from the inputs, it is a major problem since some of the calculated fields depend on many more inputs. Computer structured query language (SQL) routines are used to firstly extract the input fields required for the calculations. For simple calculations (such as density) this may imply a few queries, but for complex calculations (such as pay-factors) this may mean many more queries required for a final calculation. Each query generates a subset of data that is then linked by primary keys that are unique to the data, usually the project number and sample number. Calculation queries are then run on these sub-queries ensuring this linkage. The database creates temporary tables in the background to perform these calculations that take up a significant amount of time and computer memory. In the end the user is primarily interested in the calculated fields but these are not readily available. Furthermore, all input fields required for a final calculation must be free of errors if the calculation performed by the SQL is to succeed. Unfortunately, many fields are left empty or *NULL* requiring a check in the calculation query to flag division by zero errors.

Inefficient database structure: The QC/QA table in the SiteManager database uses field serial numbers to identify the different material properties stored in the database. Furthermore, these serial numbers are not consistent for the pre- and post-2004 spreadsheet templates. If the user, for example, is interested in the asphalt content for mixtures from the database, the unique field numbers in the corresponding pre- and post-2004 spreadsheet templates must be known, thus the necessity of a lookup table as indicated previously. As new material properties are introduced (such as Hamburg Wheel Tracking Device (HWTD) cycles in 2004) these are given new serial numbers. A more efficient approach would be to define field names for each of the material properties that are stored in the database and to use more than one database table to store these fields. Oracle, the database used to store SiteManager QC/QA data, is not restricted to 256 fields per database table like Microsoft Access. Furthermore, Microsoft Excel, the spreadsheet software used for the database templates has XML capabilities that allow spreadsheet cells to be linked to database fields. The use of serial numbers for the HMA properties complicates the understanding of the SiteManager QC/QA table and in the author's opinion is not really necessary.

No modular structure: The addition of special specifications and new asphalt mixtures results in a major problem in updating the current spreadsheet templates used for SiteManager. Using a modular programming approach will allow these new mixtures to be added more easily. These need not be hard-coded into the spreadsheet but can be linked via an XML datasheet that can be edited separately and attached at runtime.

The above listing of drawbacks is not meant as criticism but is provided simply to suggest improvements to the current SiteManager database structure to make it more efficient. It was necessary as part of the current project to develop a thorough understanding of the

SiteManager tables and database structure. The authors appreciate and understand the complexity of the SiteManager system and commend the developers in what has been achieved up until now. Clearly it was no easy task putting it all together. These suggestions are therefore provided as recommendations to improve SiteManager solely for querying purposes.

2.4 TRM GIS Database

The TRM GIS database consists of a table of Texas Reference Markers (TRM) with corresponding longitude and latitude coordinates. The structure of this table is shown in Table 2.10.

Table 2.10: TRM GIS Database TRM Table

Field	Format	Description
RM	nvarchar(4)	Reference marker number
RMDISP	float(8)	Reference number marker displacement
LATITUDE	float(8)	Latitude coordinate
LONGITUDE	float(8)	Longitude coordinate
ELEV	float(8)	Elevation coordinate
DFO	float(8)	Distance from origin
COUNTY_NUM	int(4)	County number
RTE_NM	nvarchar(10)	Route name

An important aspect to consider for TRM locations in Texas is that they are not necessarily fixed and may vary as a result of relocation of a route, environmental hazards, etc. Since the performance information for a road in the PMIS database is recorded for a specific TRM interval, for accuracy, it is necessary to also track the year the TRM information was recorded to reflect possible changes in TRM location over time. TxDOT maintains and updates the TRM database as necessary. The TRM information reported and used as part of this study was that as provided to the researchers by TxDOT in 2007.

The route name and county numbers in the TRM GIS table can be used to locate the beginning and ending extents of an HMA project if this information is not provided in the SiteManager or DCIS Projects table. Application of the TRM GIS table was a significant development in the current project and is illustrated in more detail in the next section of the report, which discusses the software developed as part of the research. Following a discussion of the software application, the report outlines the database queries developed to extract data from the databases.

2.5 SQL Queries

Communication between the application front-end and the database server is done through Python scripts installed on the server. The Python scripts call stored procedures that run SQL queries on the database server. Ultimately the application is geared towards extracting performance information for the SiteManager projects. To achieve this goal, a number of SQL queries were developed. This section outlines these queries and the steps taken to ultimately link the SiteManager and PMIS databases.

As described previously, SiteManager includes (i) a QCQA table of information collected during the design and construction of TxDOT projects, (ii) a CCSJ table providing specific project information, and (iii) an Items List table that includes project price and quantity information. A query was developed to link these three tables as shown in Figure 2.3. This allows the QC/QA data to be related to a specific SiteManager project and at the same time provides price and quantity information for the project. This query was named **GEN_SMPRJS**.

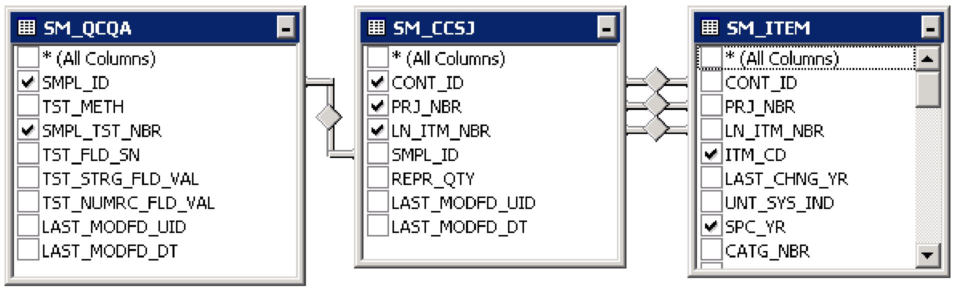


*Figure 2.3: SQL Query linking the SiteManager Databases (**GEN_SMPRJS**)*

The quantity and pricing information in the SiteManager Items List table *could* be used to ensure that sufficient quantities of asphalt were required for paving. This could be used as a measure to eliminate those projects on which smaller quantities are used for patching or other repairs.

In addition to the three tables mentioned above, SiteManager also includes a Project table with descriptive information pertaining to the location of the project. Unfortunately, this table is not well populated and for this reason it was decided instead to include the Projects table from the DCIS database, which is more complete. A link was then established between the DCIS Projects table and the GEN_SMPRJS query as shown in Figure 2.4. A District and County table was also linked, as shown, to provide names for corresponding district and county numbers provided in the DCIS Projects table. This query was named **GEN_SMPRJSINFO**.

This shortcoming should be addressed by updating the Projects table in SiteManager. This would negate the required use of the DCIS Projects table that will reduce the resources required to maintain the application, particularly when updating the application databases.

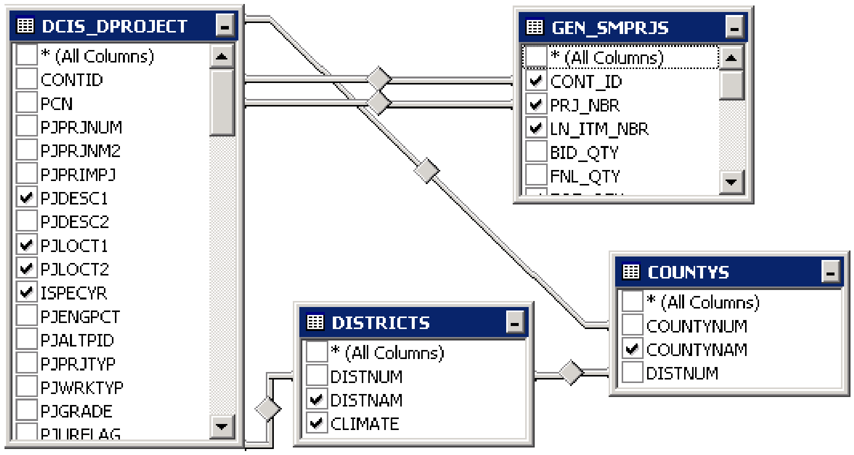


*Figure 2.4: SQL Query linking the DCIS Project Table (**GEN_SMPRJSINFO**)*

In Figure 2.4 it can be seen that the DCIS Project table includes a description of the project (PJDESC1) as well as descriptions of the project extents defining the beginning (PJLOCT1) and ending (PJLOCT2) locations. These descriptions are used to determine GIS coordinates as well as TRMs for the SiteManager projects as is explained in the next chapter of the report. The GIS and TRM information collected is stored within a database table called **COORDS**. The fields in this table are shown in Table 2.11.

Table 2.11: Application COORDS Table

Field	Format	Description
CONTID	nvarchar(15)	Project control section job
PCN	nvarchar(13)	Project control number
BLONG	float(8)	Beginning point longitude
BLAT	float(8)	Beginning point latitude
ELONG	float(8)	Ending point longitude
ELAT	float(8)	Ending point latitude
BRM	float(8)	Beginning point reference marker
BDISP	float(8)	Beginning point reference marker displacement
ERM	float(8)	Ending point reference marker
EDISP	float(8)	Ending point reference marker displacement
LANE	smallint(2)	Undivided (1), divided mainlanes (2) divided frontage roads (3)

The **COORDS** table is a listing of those SiteManager projects that are included in the application. This table currently includes 500 projects and it is for these projects that the performance information is reported and on which the statistical analyses (to be described in the next chapter) are run.

To establish *point* location information for the SiteManager projects, the GIS and TRM information from the **COORDS** table is linked to the previous query **GEN_SMPRJSINFO** as shown in Figure 2.5. This query was named **GEN_DB_PRJS**.

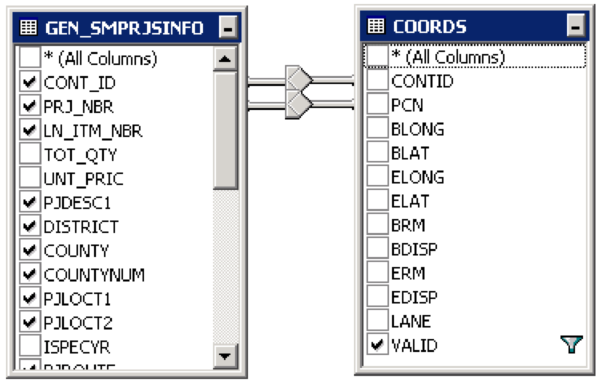


Figure 2.5: SQL Query linking GEN_SMPRJSINFO and COORDS (GEN_DB_PRJS)

The final step in the process is establishing the link between **GEN_DB_PRJS** and the **PMIS** database. This is somewhat trivial since the TRM information in **GEN_DB_PRJS** can be linked to the TRM information in the **PMIS** database. There are, however, a few constraints to consider:

- Route names in the SiteManager and PMIS tables must match. The differences in route naming conventions in these two tables must be taken into account. For example, from Table 2.5 it can be seen that state highway loops begin with the code SL whereas in the SiteManager and DCIS databases these begin with the code LP. In addition, alternative routes in PMIS are named using the codes UA, SA, etc. whereas alternative routes in SiteManager and DCIS have an "A" following the route name, e.g. US 90A.
- Matching TRMs. Only PMIS data that falls within the SiteManager project's extents (TRM ± Displacement) should be used.
- The PMIS roadbed IDs shown in Table 2.6 must match the roadbed identified for the SiteManager project.
- Only asphalt concrete pavement types as listed in PMIS should be considered.

A listing of the SQL query linking the SiteManager and PMIS tables is provided as an Appendix to the report.

Chapter 3. Software Development and Application

This section outlines the software developments done as part of the project. An overview of the application deployment is provided before discussing the various software components in more detail.

3.1 Application Deployment

Figure 3.1 illustrates the model applied for deployment of the application. The application was developed as a web-based GIS front-end to query the databases discussed previously and provide the results of these queries to users that access the application over the internet.

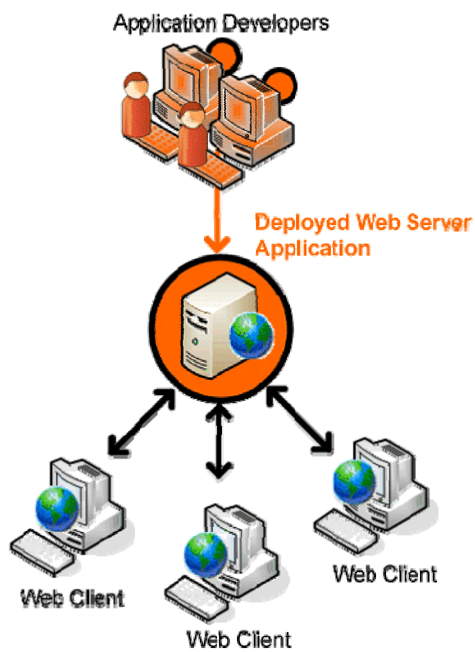


Figure 3.1: Application Deployment

The software development and deployment products used for the application were extensively researched before use. This was done specifically to identify the best tools for the job. In fact, none of the final products applied had previously been used in any software developments done by the project team. It was to go through a learning curve to determine how to best apply these tools to the task at hand. The challenges presented to meet the objectives of this project and specifically the application of a statistical module within the software required the use of innovative approaches to the problem. This could not be achieved using conventional approaches typically applied for server-client applications and consequently the application, as developed, cannot easily be deployed within typical networking environments— such as the TxDOT intranet. As is outlined below, the application requires a specific networking environment or framework to function, and consequently some minor changes to existing frameworks may need to be made for the successful deployment of the application.

The application as a whole consists of a front-end that runs from web clients through an internet browser. The browser connects to a web server that in turn runs software scripts programmed to connect and query a database server. The database server returns the result of the query to the software script which then returns the data to the browser. The client manipulates the data and reports it to the user in the form of tables and charts. This flow of information from client-server-client is illustrated in Figure 3.2.

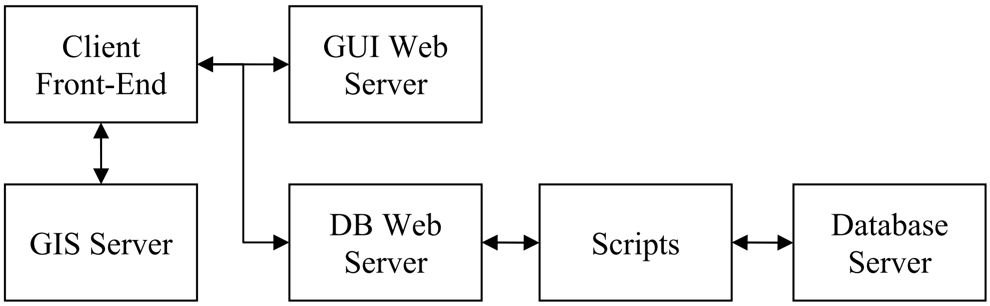


Figure 3.2: Application Data Flow

Figure 3.2 shows the client client-server setup used for the application. For deployment of the application, the researchers purchased and installed a server running the Windows Server 2003 operating system (OS) although the application could be installed on any OS including Linux. This server was installed within the Civil Engineering network domain at The University of Texas at Austin (UT-Austin) and a static internet protocol (IP) address was registered to allow direct communication with the server: http://pavements.ce.utexas.edu. As such, the security of the server is maintained by the Department of Civil Engineering but the researchers had direct administrative access to the server, which was critical during the application development stage.

From Figure 3.2 it can be seen that the application makes use of two separate web servers. The first web server used was the Microsoft Internet Information Services (IIS) component that is shipped with the Microsoft OS and runs off port 80. This serves the application graphical user interface (GUI) or front-end. The application front-end can be reached from the following internet address: http://pavements.ce.uytexas.edu/TxDB/TxDB.html. When the user connects to this address, the IIS web server uploads a copy of the application to the user or client's computer. The client then runs this application through the browser showing the GUI.

The GUI was developed using Adobe Flex (http://en.wikipedia.org/wiki/Adobe_Flex). This is a user-friendly web authoring product for the rapid development of so-called RIA or rich internet applications (http://en.wikipedia.org/wiki/Rich_Internet_application). RIAs run from a web browser but have the look and feel of an application that is run from the user's desktop. In order to run Adobe Flex applications, users must have Adobe Flash player installed on their systems. Adobe Flex provided the necessary components to allow users to query the application and the table and charting functions necessary to report the application data. In addition, ESRI (http://www.esri.com) provides a mapping component that can very easily be implemented within Flex applications. The ESRI mapping component communicates directly with a GIS server over the internet (http://www.**arcweb**services.com). This component is built into the Flex application and as such allows communication directly between the client and ESRI's mapping server without having to pass through the UTA web servers. Flex is open-source software and Flex Builder, an integrated development environment (IDE) for Flex is provided to University students and staff at no cost.

The second web server shown in Figure 3.2 is an Apache (http://httpd.apache.org) server that runs off port 8080. It was necessary to install this web server in addition to the IIS web server because the latter does not provide an interface to interpret Python scripts. Apache provides a module (http://www.modpython.org) that can interpret Python scripts directly. Given this requirement it is necessary that the application be deployed from a server with Apache installed. The GUI may also be served through the Apache server.

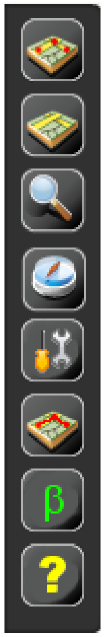
The decision to use Python (http://www.python.org) as the scripting language for the application was primarily based on the availability of Python modules to communicate with the database through the Flex application and modules for the application of the statistical analyses procedures developed as part of the project. Python provides the numPy (http://numpy.scipy.org) module that was essential for the fast and accurate numerical analysis of several thousand data points generated for the statistical analysis of performance measures. This analysis is run on the server and the results are passed back to the client within seconds. The authors are not aware of other scripting environments that provide this functionality.

Microsoft SQL 2000 is the database server used. The databases used as part of the project (DCIS, PMIS, SiteManager, and TRMGIS) were copied to this database server that also contains all of the SQL scripts developed as part of the project.

3.2 The GUI Front-End

A GUI may be seen as the control panel of an application. It allows the user to easily set and change parameters that are then passed to the application. A web-based application typically runs through a browser and as such, the GUI can be programmed in any computer language that provides browser components such as HTML, ASP, .NET, PHP, or Java. In addition to setting parameters through selection boxes, drop-down menus, buttons, etc. the GUI must provide components to report the results passed to the client from the server— typically in tables or charts. The decision to use Flex instead of these other programming languages was because it provides these reporting components out of the box. Flex applications afford a more professional look and feel that is often difficult to achieve using other web-based programming languages.

The GUI of the application, developed as part of the project, shows a map of Texas in the background with an application bar as shown in Figure 3.3. The application bar has a number of clickable icons, each of which performs a specific function. The reader is referred to the User's Manual for a more detailed explanation on how to use the application. What follows is a brief overview of the different application functions.



- Section filter and queries.

- Various base maps.

- Find function.

- Navigation used to pan and scale the map.

- Tools used primarily for data input.

- Section limits. Used to list or edit sections.

- Statistical functions for performance analyses.

- Help includes user's manual and video tutorials.

Figure 3.3: Application Bar

Project Filter and Query Function

This function provides the user the option to select and filter TxDOT projects that can be "marked" on the underlying map. Currently, the projects may be filtered based on different criteria including (i) location information such as district, county, facility type, and climatic region; (ii) material information such as mix type, binder grade, specification year, and construction date; and (iii) material properties such as asphalt content, laboratory and field density, voids in the mineral aggregate (VMA), and thickness. The material properties filter provides the option to list projects that fall within specific ranges, for example projects with asphalt contents between 4 and 5 percent. Furthermore, the filter criteria may be set collectively, i.e., multiple filters may be applied to only show projects that meet each of the set criteria.

Figure 3.4 shows all the SiteManager projects currently identified by the application marked on the map of Texas. In total, the application currently includes 500 SiteManager projects spread throughout Texas. The majority of the SiteManager projects listed were constructed in Texas from 2004 onwards.

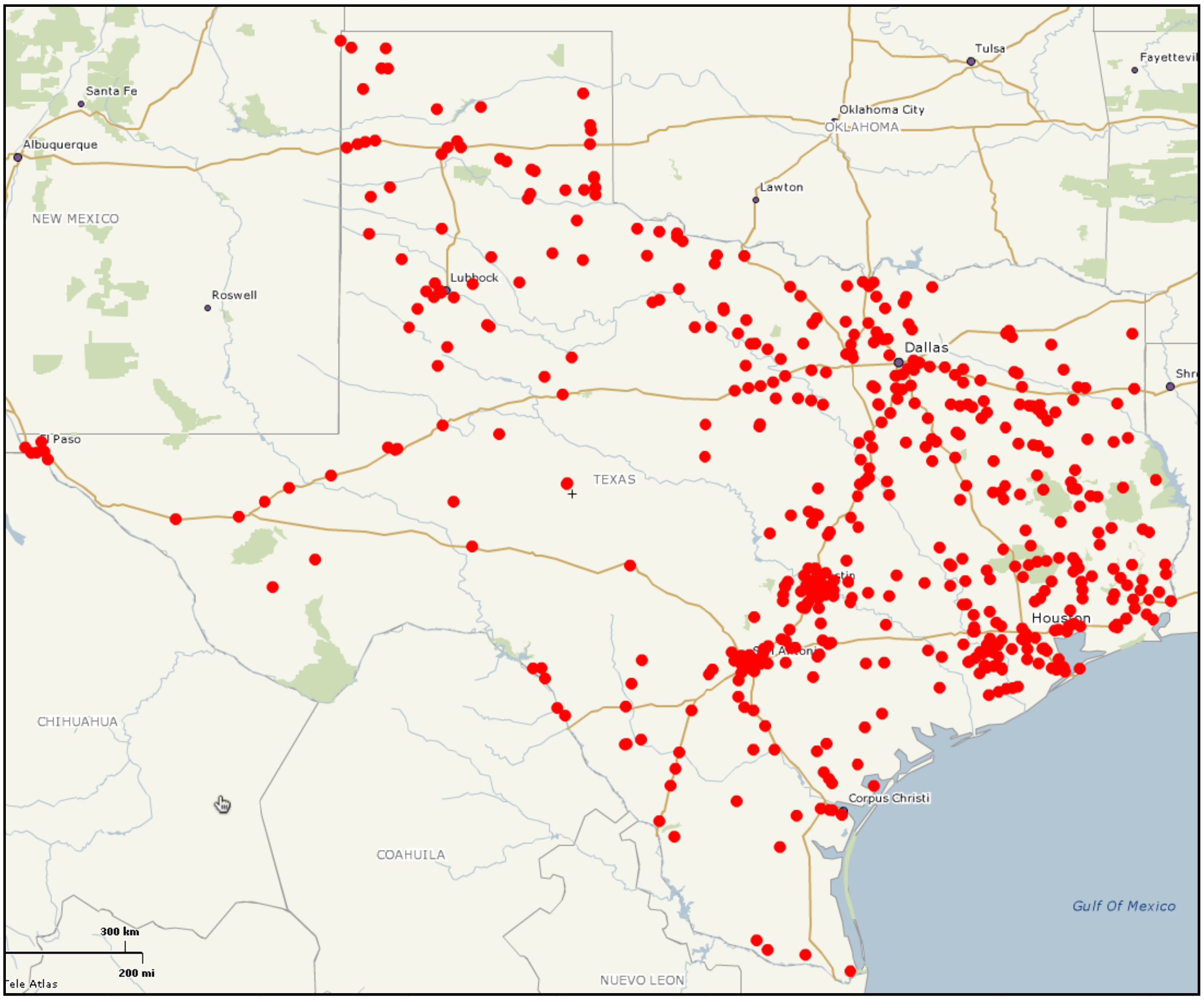


Figure 3.4: Application SiteManager Projects

Project Reporting Function

Each marker on the underlying map represents a project "object". By moving the mouse cursor over a marker the control section job number of the project identified by the marker is shown. If the marker is clicked it will open up a dialog box that reports information relevant to the project. Each dialog box includes general information relevant to the project as well as tables and charts of performance, design, and construction information. Figure 3.5 shows examples of these dialogs. Dialog boxes may be opened for multiple projects. This allows the properties and performance measures of the different projects to be compared side-by-side.

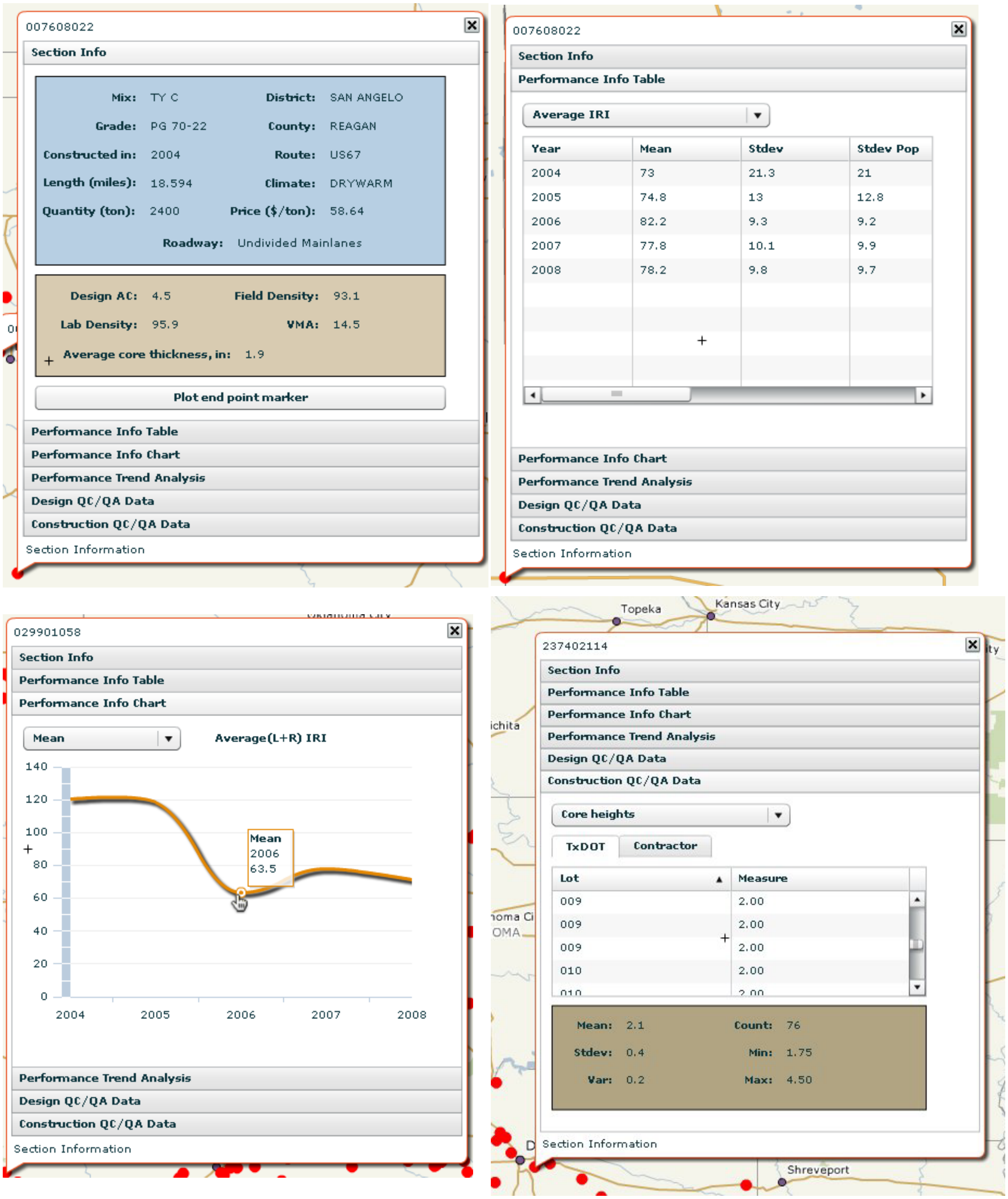


Figure 3.5: Application Reporting Dialogs

3.3 Comparing the Performance of Different Asphalt Mixtures

One of the objectives of the project was to provide a tool to compare the relative performance of different asphalt mixtures. The project filtering function of the application provides the ability to select projects for comparison. Using this function allows the performance measures of two or more projects to be compared directly, albeit visually. Any of the network-level performance measures listed in Section 2.1.1 of this report (rutting, cracking, roughness, etc.) may be used for comparison.

Comparing the relative performance of projects should consider a number of factors that may influence the performance of any particular mixture used on a project. This includes not only the traffic and climatic conditions to which a mixture is subjected, the past service life of the mixture, design and construction properties, but also the underlying structure on which the mixture is paved. Discretion is therefore required to ensure that projects are compared fairly. The application dialogs provide most of the functions necessary to review the various factors that may influence a mixtures performance. Furthermore, a statistical function is provided that allows a more thorough comparison of mixture performance. This is discussed in more detail later in the report.

3.4 Performance Trend Analysis

The application provides a function to investigate the performance trends of SiteManager projects. The anticipated future performance of a project may be forecast based on past performance measures. This is done by fitting a linear, quadratic, or exponential function to available performance measures and estimating or predicting the performance at a future date based on the best fit of these models. Figure 3.6 shows the performance trend analysis of average IRI for a particular SiteManager project constructed in 2004.

The accuracy of the performance trends is significantly influenced by the initial performance measurement and the user must indicate the start date from when to begin the forecast. The start date for performance predictions would typically be the date when construction of the project was completed. The end-of-construction date, however, may not necessarily be the same as the date when the first PMIS measurement following construction of the project was done, as is illustrated in Figure 3.6. In this figure the actual IRI of the project is shown to rapidly decrease from 2004 to 2005 followed by a gradual increase through 2008. The initial drop in IRI is what one would expect following rehabilitation of a roadway. The newer road would be smoother than the old one. Over time one would expect the roughness of the road to increase as the pavement ages. This too is the case. Thus, although the project shown in Figure 3.6 may have been constructed in 2004, the first PMIS measurement was only taken in 2005; hence 2005 would be a better choice for the start date from which to begin the trend forecast.

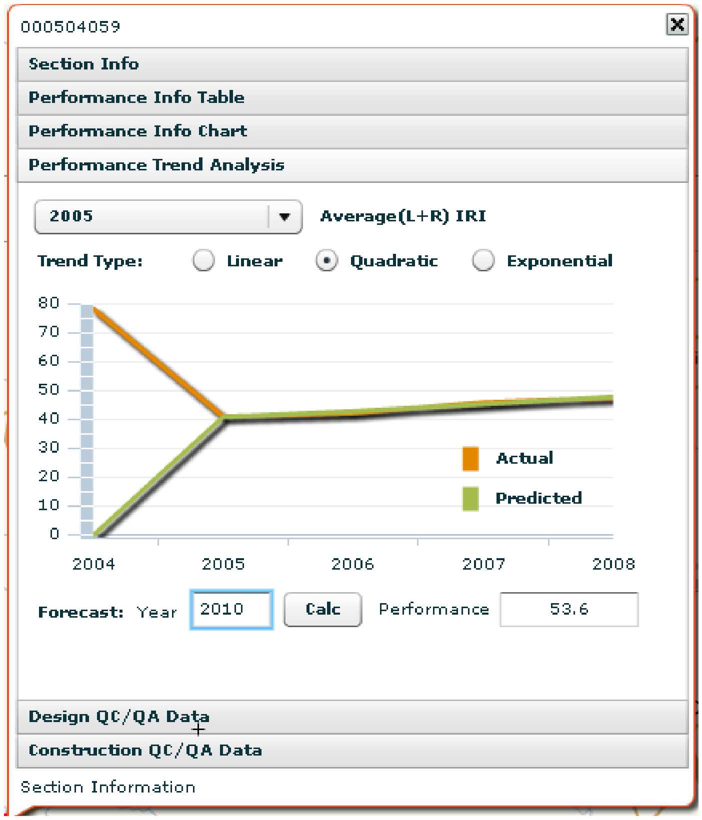


Figure 3.6: Performance Trend Analysis

3.5 Inputting SiteManager Projects

The application provides the functions necessary to input new SiteManager projects. The database currently includes SiteManager projects constructed from 2004 through July 2008. As new TxDOT projects are constructed on a monthly basis, the application database should be updated from time to time to include these new projects. Once the application database has been updated, the application may be used to input these new projects into the system. This process is outlined in the application User's manual.

The application provides various tools to assist the user with the input of new SiteManager projects. This ensures that a link can be established between the SiteManager and PMIS databases. To provide this link, the user must be able to identify the beginning and ending Texas Reference Markers (TRMs) of the SiteManager project. This is necessary to be able to communicate with PMIS. In addition, to allow the geographical positioning of the project, the longitude and latitude of the beginning and ending points of the project must be defined.

The description fields in the DCIS Project table provide a description of the beginning (from) and ending (to) locations, textually describing the extents of the project. These descriptions may include street names, county lines, or other physical locations that may be used to trace or locate these extents on the underlying map. In addition to the base street maps, the application also provides satellite aerial photography and topographical maps to aid the user in locating project extents. Once these extents are defined, the longitude and latitude coordinates of the beginning and ending points of the project may be retrieved directly from the underlying map. If the DCIS Projects table does not provide the TRMs for the project, these may be determined indirectly.

One way to retrieve TRMs for a SiteManager project involves plotting the TRMs along the project route and calculating the distance from the project extents to these TRMs. If the route and county in which the project is located is known, all the TRMS along that route and within that county may be plotted on the underlying map. This is demonstrated in Figure 3.7 that shows the TRMs along US 181 in Bee County. The mouse pointer has been placed over one of the TRMs at reference marker 596. Note that for illustrative purposes the map has been rotated to show the TRMs horizontally along the map.

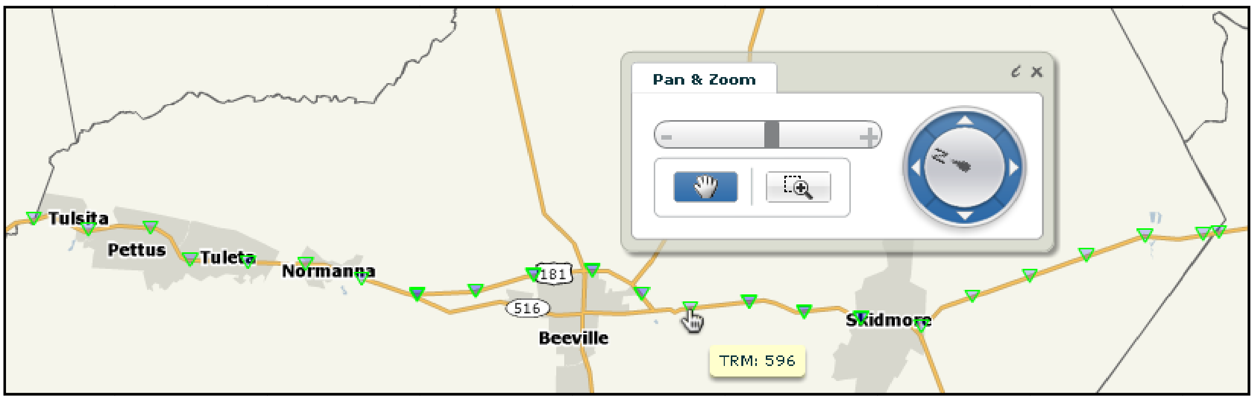


Figure 3.7: Plotting TRMs

TRMs in Texas run from state line to state line and start from the westernmost or northernmost point of the highway origin for all roads except interstate highways which are numbered south to north. If the project extent falls between or within a reasonable distance from a TRM marked on the underlying map, the distance from the project extent and the TRM can be determined to define the TRM of the project extent. This typically would include a displacement (positive or negative) from the marked TRM. Distances between two points on the map are determined by calculating the geodesic distance (in miles) between the points specified by longitude and latitude coordinates. The function used in the application to determine distances between two points makes use of the Vincenty inverse formula for ellipsoids. This equation takes into account the curvature of the earth and provides an accurate estimate of distances between points that are close and far apart (http://en.wikipedia.org/wiki/Vincenty%27s_formulae).

Measuring the distance between points is also useful if the length of the project is available. The application provides a function to trace a line along a route and to measure the cumulative distance from a particular starting point. The length of SiteManager projects is an important parameter to consider when inputting new projects. PMIS data is collected every 0.1 miles; therefore a 3-mile long section will provide 30 performance measurements along the section. Shorter sections may not provide sufficient data for statistical analyses. As a general guideline it is recommended that only SiteManager sections at least 3-miles in length be considered in the application. Furthermore, the length of a SiteManager project should be considered together with the quantity of asphalt concrete placed during construction. This may be useful to indicate the relative thickness and extent of the project. The user should also be aware that the lengths of some SiteManager projects are incorrectly listed as zero when in fact the project extends several miles. In some cases, a project length of zero is listed if the SiteManager project entails county or state-wide repairs. These particular projects should not be considered in the application.

In addition to the GIS coordinates and TRM information, the user must indicate the roadway on which the project is constructed. This may be on (i) an undivided roadway, (ii) a divided mainlane, or (iii) on frontage roads on a divided roadway. The description field in the DCIS table may indicate on which roadway the project is constructed. The underlying map may also be scaled to show whether the roadway is divided or not— divided roadways show as two distinct lines on the application base street maps when scaled to 200 feet. For interstate highways with frontage roads it was assumed that construction always occurred on the mainlanes if this was not indicated in the Project table. The user may, however, not wish to enter a SiteManager project if this information is not known as this may lead to errors or inaccuracies when determining the performance of a roadway that was mistakenly identified to be on the incorrect lane.

SiteManager projects may be input directly from the application front-end. Projects may also be edited directly from the front-end. The ability to enter or change data in the application database is considered an administrative privilege and application administrators will require a user identification and password in order to input SiteManager projects or edit existing projects.

3.6 Statistical Analysis of Performance

The statistics application is opened from the βeta icon shown on the application bar. In contrast to the project selection and filtering functions that can be used to summarize performance trends for individual sections, the statistics function is used to provide an overall summary based on all of the projects in the application database. The application's statistics dialog, pictured in Figure 3.8, shows how different variables that can be included in a statistical analysis are grouped in separate containers. Currently the statistical application allows for the analysis of various influence factors including asphalt mix type, facility type, climate, low and high temperature grade, as well as various material properties and loading conditions. Response variables are the network-level performance measures (rutting, cracking, roughness, etc.) as previously listed in Section 2.1.1 of the report. Running a statistical analysis requires selection of the influence and response variables and clicking the *Run* button provided on the dialog. The information is sent to the server, processed, and the results of the statistical analysis sent back to the client in the format shown in Figure 3.9.

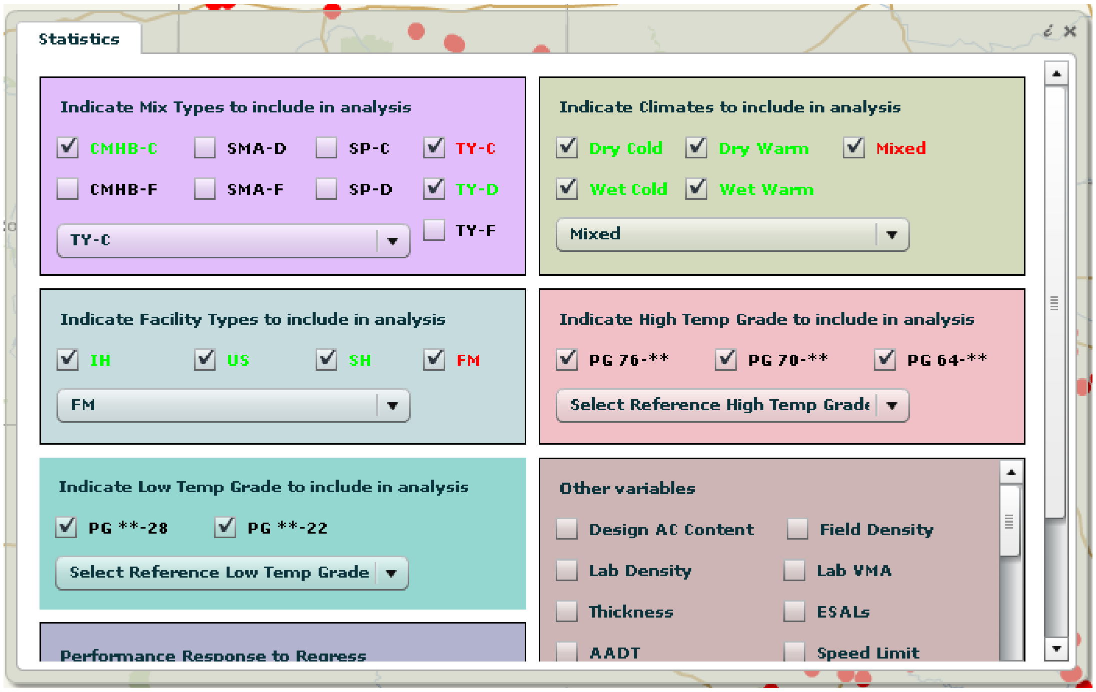


Figure 3.8: Application Statistics Dialog

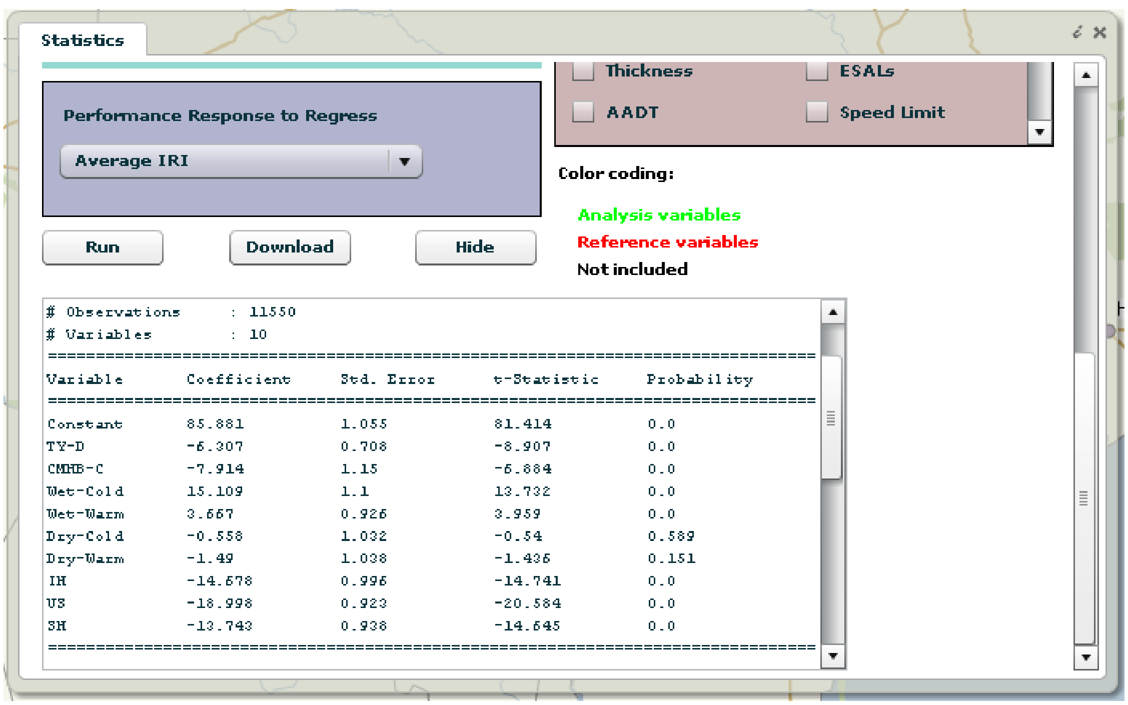


Figure 3.9: Application Statistics Dialog

The statistics analysis function is programmed to run through a Python module that performs a regression analysis on data passed to the server. The analysis is run on the server to obtain the coefficients of the linear equation $y_i = a + b\,x_i$. These are determined using a least-squares approach. The output indicates the dependent or response variable, the number of observations, and the number of variables included in the regression analysis. The calculated coefficients, standard errors, t-statistics, and probabilities of the independent variables are provided as output. The statistical output also includes some model and residual statistics. It is left to the user to interpret the results of the analysis although the User's manual provides an example with some guidelines to assist in the interpretation of the results. The application's statistics function does perform some error checking to ensure that the data being analyzed is valid but does not currently check for highly correlated variables.

Source code for the application, as well as the Python scripts used to communicate with the database server and to run the trend and statistical analyses, has been provided to TxDOT. The next chapter further addresses the statistical analysis of SiteManager projects to investigate the influence of different variables on the performance of asphalt mixtures.

3.7 Database Integration

The application, as developed, currently connects to the TxDOT databases installed on the UT-Austin server. These are snapshots of the TxDOT mainframe databases that were manually imported from copies received from the Project Director outside of the TxDOT infrastructure. It is critical, therefore, to maintain these databases by updating them on a regular basis, particularly the SiteManager database. The need for manual updates is a shortcoming that should be addressed. It is therefore recommended that the application, as developed, be given access to TxDOT databases such as the temporary Sybase databases created from DCIS and SiteManager. These temporary or ad-hoc databases are generated on a daily basis from the mainframe databases and would provide up-to-date records and eliminate the need for manual updates.

Chapter 4. Statistical Analysis of HMA Performance

This chapter describes the statistical analyses that were performed at the various stages of the project and their most significant results. Three different analyses were performed based on three different sets of data, which were available at the various stages of the project. For each set of data, numerous analyses were performed but, for the sake of succinctness, only some examples are presented in this chapter.

The first analysis was performed on the original dataset that consisted of the hot-mix asphalt projects in DCIS that had location information in terms of TRM. In this case, the results of the analysis of the roughness data are presented in Section 4.1. The second analysis was performed based on the section whose location was determined by using the Corridor Analysis Program (CAP). CAP facilitated the determination of distance-from-origin (DFO) of various projects in DCIS. DFO was in turn related to TRM, which enabled the link with PMIS information. In this case the analysis of cracking data is presented (Section 4.2). Finally, the third analysis was carried out on the dataset that was obtained after the incorporation of the data from SiteManager. In this case results of roughness (in IRI), ride, cracking, and rutting are presented in Section 4.3.

4.1 Roughness Analysis of DCIS Sections

This analysis was one of the first statistical analyses performed as part of this research project and included data from those hot-mix asphalt projects for which DCIS contained location information, some 6,639 individual PMIS sections. As mentioned earlier, this accounted for less than ten percent of the total projects in DCIS at the time. Figure 4.1 represents the relative distribution per District of these 6,639 sections, which spanned back to 1993.

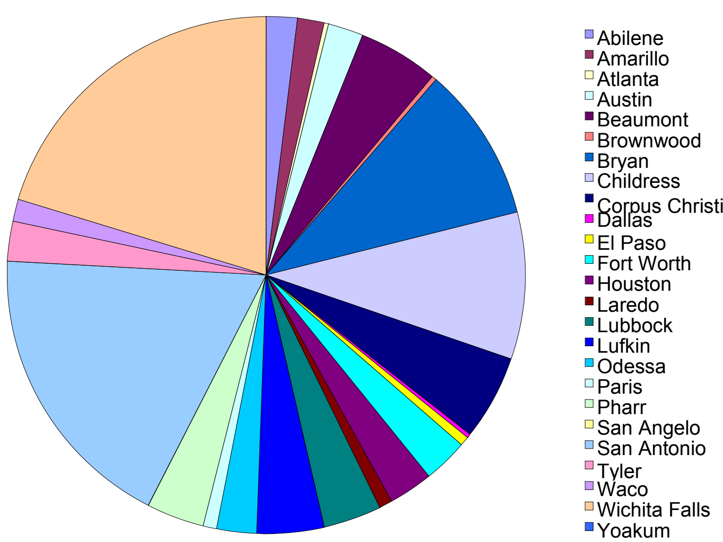
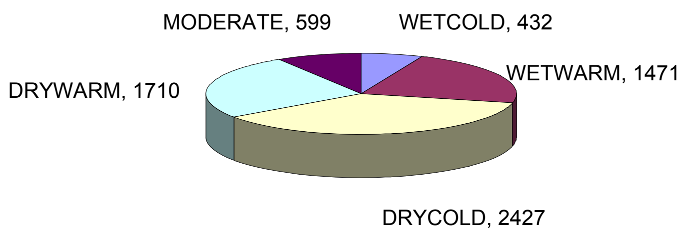


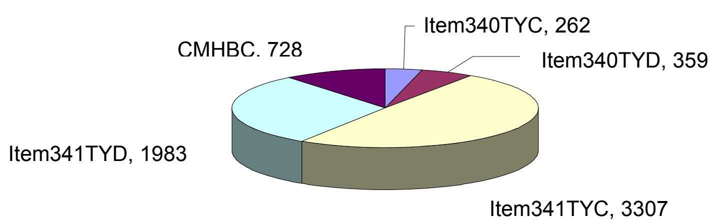
Figure 4.1: Section Distribution per District

The sections represented in Figure 4.1 do not include all hot-mix projects available in DCIS, but only those for which at least three years of performance data was available in PMIS. Thus, the total sample size was 30,407, including performance measurements of the projects over time. The projects as defined are therefore sections of the PMIS roadway within specific TRM limits. In addition, it should be noted that, depending on the length of the project, several performance data points were available. This analysis, however, is based on the average performance for the PMIS section of roadway within the TRM limits of the project.

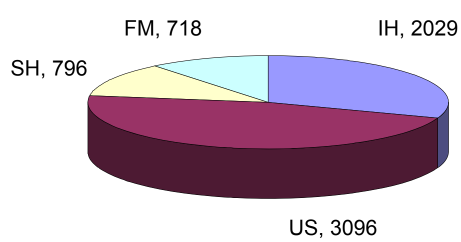
Figure 4.2 shows the breakdown distribution of the analyzed projects according to various characteristics such as: (a) environmental region, (b) mixture type, and (c) highway system. It can be observed that there is a fair representation of each characteristic, with the dry-cold region, Type C mixtures, and the US Highway system being the most frequent. Only mixture types for which there were sufficient data are included. For this reason, for example, Superpave, PFC and SMA mixtures are excluded since there were only a limited number of projects using these mixtures at the time.



(a) by Environment



(b) by Mix Type



(c) by Highway System

Figure 4.2: Mixture Distribution According to Various Characteristics

For the statistical analysis reported herein, the following independent variables were considered: (i) environmental/climatic region at five levels (wet-cold (*WCo*), wet-warm (*WWa*), dry-cold (*DCo*), dry-warm (*DWa*), and mix), (ii) mixture type at three levels (Type C, Type D and CMHB-C), (iii) specification type (either Item 340 or Item 341), (iv) highway system at four levels (*FM, SH, US, IH*), (v) traffic level (*Traf*), and (vi) amount of maintenance (*Main*), which was the dollar value spent to maintain the entire project. The dependent variable in this case was roughness in IRI according to the following general linear model specification:

$$IRI = \beta_0 + \beta_1 Traf + \beta_2 Main + \beta_3 WCo + \beta_4 WWa + \beta_5 DCo + \beta_6 DWa + \beta_7 340C + \beta_8 340D \quad (4.1)$$
$$+ \beta_9 341C + \beta_{10} 341D + \beta_{11} IH + \beta_{12} US + \beta_{13} SH$$

where 340C, 340D, 341C and 341D are used to represent Type C and Type D mixes under Items 340 or 341, respectively. The rest of the variables are described above.

This model was developed to capture the average roughness per project over time and how this average is affected by each of the variables considered. Thus, if the corresponding coefficient (β) of a variable is positive and significantly different from zero (t-Stat larger than approximately 2.0 or P-value smaller than 0.05), the corresponding variable contributes significantly to increase roughness. It should be noted that not all variables are explicitly incorporated into the model. CMHB-C mixes, FM highway system, and mix environment are apparently missing. However, the intercept term (β_0) in the model presented in Equation 4.1 captures the average roughness condition in IRI for a reference dataset, which, in this case, consists of CMHB-C mixtures on the FM system in the moderate environmental region (Central Texas). This does not necessarily represent a particular pavement type but sets a reference point for benchmarking the other variables relative to the reference variables. Thus, the influence of each variable is determined relative to the reference variables. The results of this analysis are given in Figure 4.3. Figure 4.3 is the output summary table of the results of the statistical analysis performed using MS Excel. The following are the most interesting findings of this analysis:

1) All variables considered are significant; however, not all have the expected signs.
2) Traffic is associated with increased roughness (the more traffic, the rougher the road).
3) Maintenance activities (in dollars) are also associated with increased roughness. This can be interpreted as follows: the rougher the road, the more TxDOT has to spend on it. This interpretation, however, has to be taken lightly since no information about the specific type of maintenance work is available at this time.
4) The wet-warm region seems to be the worst in terms of roughness, while Central Texas (mixed/moderate environment) seems to be the best condition.
5) The interstate system (IH) is maintained in better conditions than the US system, which in turn is better than the state highway system (SH). The FM system seems to be the roughest.

Regression Statistics	
Multiple R	0.41
R Square	0.17
Adjusted R Square	0.16
Standard Error	26.79
Observations	6,639

ANOVA	df	SS	MS	F
Regression	13	949,254	73,019.5	101.8
Residual	6,625	4,753,886	717.6	
Total	6,638	5,703,140		

	Coefficients	Standard Error	t Stat	P-value
Intercept	68.30	2.09	32.7	6.9E-218
Traff_M	0.00061	0.00006	10.7	1.1E-26
Maint_M	0.00344	0.00027	12.5	2.0E-35
WETCOLD	8.50	1.80	4.7	2.5E-06
WETWARM	18.16	1.47	12.3	1.8E-34
DRYCOLD	9.92	1.29	7.7	2.0E-14
DRYWARM	8.98	1.44	6.3	4.3E-10
Item340TYC	12.82	2.07	6.2	6.7E-10
Item340TYD	22.34	1.85	12.1	3.1E-33
Item341TYC	18.66	1.30	14.4	4.8E-46
Item341TYD	15.67	1.36	11.5	2.3E-30
IH	-29.60	1.70	-17.4	2.4E-66
US	-23.87	1.37	-17.5	6.7E-67
SH	-10.86	1.45	-7.5	9.6E-14

Figure 4.3: Results of the Roughness Analysis

The findings above should be interpreted only as interim results. Further statistical analysis including cross terms effects, should be included. In addition, it should be emphasized that the data for this analysis has been aggregated and treated at a network-level and several assumptions had to be made. One of the main assumptions is that the DCIS material data and the PMIS performance data correspond to the same highway lane. This assumption, although true in the majority of cases, does not necessarily hold true. The network-level analysis should be robust enough to cancel out random errors; however, if systematic errors are present, the analysis will not be able to pick those out.

This dataset (6,639 sections) was also analyzed to establish roughness trends, that is, the rate at which roughness changes with traffic or time. For this case, the following simple regression model was utilized:

$$IRI = \beta_0 + \beta_1 T \quad \ldots \quad Eq.(4.2)$$

The parameter β_1 in Equation 4.2 captures the change of roughness with time or slope. The value of this parameter was estimated for each project for which at least three years of performance data was available. Figure 4.4 shows the histogram of the 6,639 slopes calculated. Although roughness should increase with time, a large number of negative slopes can be observed. This is because, unfortunately, PMIS does not capture maintenance and rehabilitation activities, nor the exact time when this work is performed on the specific projects.

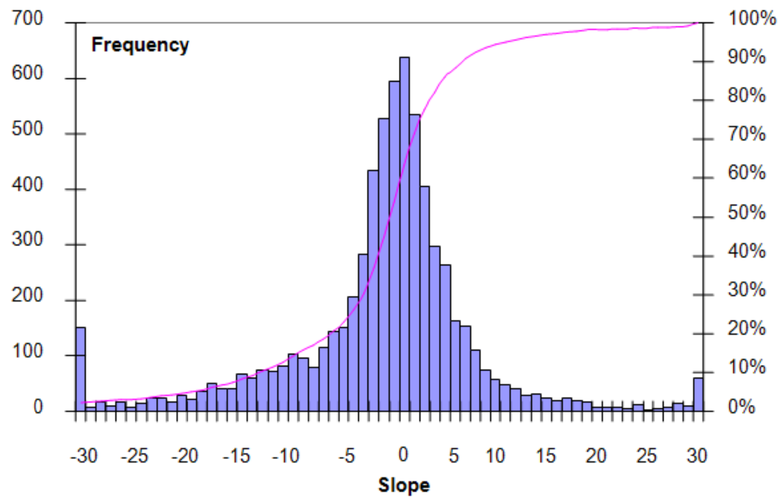


Figure 4.4: Results of the Roughness Slope Analysis

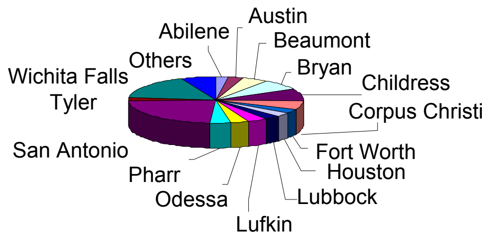
Figure 4.4 shows that 63% of the slopes are non-negative, i.e., roughness increases with time for these projects. Further analysis of the slopes revealed that only 2,900 of the 6,639 slopes were significantly different from zero at the 5% level. The slopes are necessary for the trend analysis but, with the lack of maintenance and rehabilitation records, the estimated slopes can only give an idea of the overall network condition, not the condition of individual projects. That is, if the slopes were mostly negatives, this would serve as an indication that the average pavement roughness of the network is improving. Finally, it should also be remembered that this sample represents less than ten percent of the projects contained in DCIS.

The analysis reported in this section highlighted the potential benefits of the network-level analysis; however, it also highlighted some shortcomings. The most important problems encountered were: (i) the lack of location information in DCIS (less than ten percent), (ii) inability to identify the specific lane where the projects were constructed (PMIS performance data are only available for one lane), (iii) short times series information (between three to seven years of performance were available for the analyzed sections), and (iv) the lack of detailed information on maintenance and rehabilitation activities. If the latter were available, the information could be incorporated into the model and the estimated slopes would represent the change of roughness with time (or traffic) at a project-level rather than at a network-level.

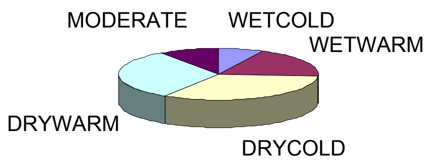
4.2 Cracking Analysis (incorporating CAP projects)

The analysis reported in this section is based on the dataset that was obtained from the Corridor Analysis Program (CAP). CAP contains a database of projects for which CCSJ are known as well as DFOs (distance-from-origin). Furthermore, PMIS contains a table that links DFOs with TRMs, thus, the link between DCIS and PMIS could be established.

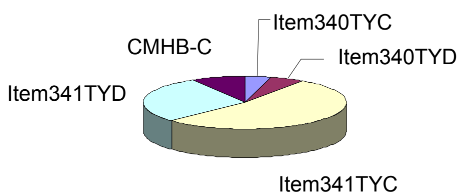
With the incorporation of the CAP database, the number of sections was increased to 7,821. For each of the PMIS sections there were at least three years of performance data. These resulted in 62,730 observations. Figure 4.5 shows the distribution of the projects according to the following characteristics: (a) location by District, (b) location by climate, (c) mixture type, and (d) by highway system (facility). As for the previous analysis, only variables having sufficient data were included in the analysis.



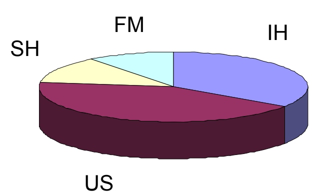
(a) By District



(b) by Climate



(c) by Mix Type



(d) by Facility Type

Figure 4.5: Distribution of sections used in the analysis

Two models equivalent to those described in Equations 4.1 and 4.2 were estimated with the exception that the dependent variable was alligator cracking (in percentage). The independent variables were traffic, maintenance, environmental region (wet-cold, wet-warm, dry-cold, dry-warm, and mix), mixture type (Type C, Type D and CMHB-C), specification type (340 or 341), and highway system (FM, SH, US, IH). Also, as before, mixed or moderate environment

(Central Texas), CMHB-C mixtures, and the FM system were used as the set of reference conditions.

Figure 4.6 shows the summary of the statistics results with the ANOVA table and the individual statistics of the model parameters. Recall that only those variables whose parameter p-value is less that 0.05 can be considered statistically significant at the 5% level. Figure 4.6 shows that, on average, maintenance, wet-warm environment, Type C (Item 340), and the Interstate highways system (IH) are not significantly different than the reference case, i.e., mixed environment, CMHB-C, and FM system. The rest of the variables seem to have a significant effect. In particular, it should be noticed that the data indicate that Type D mixes (Item 341) show less alligator cracking than Type C mixes (Item 341).

Regression Statistics	
Multiple R	0.177
R Square	0.031
Adjusted R Square	0.030
Standard Error	3.871
Observations	7821

ANOVA	*df*	*SS*	*MS*	*F*
Regression	13	3765.23	289.63	19.32
Residual	7807	117007.92	14.99	
Total	7820	120773.16		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.230	0.289	0.795	0.426
Traff_M	0.000	0.000	-2.188	0.029
Maint_M	0.000	0.000	-0.070	0.944
WETCOLD	-1.157	0.228	-5.070	0.000
WETWARM	0.125	0.193	0.646	0.518
DRYCOLD	-0.435	0.168	-2.583	0.010
DRYWARM	-0.623	0.180	-3.467	0.001
Item340TYC	0.227	0.276	0.822	0.411
Item340TYD	0.700	0.253	2.760	0.006
Item341TYC	1.401	0.186	7.523	0.000
Item341TYD	0.896	0.200	4.492	0.000
IH	0.163	0.191	0.851	0.395
US	0.632	0.179	3.533	0.000
SH	1.273	0.190	6.698	0.000

Figure 4.6: Statistics of Alligator Cracking Model incorporating CAP Data

Some of the results of this analysis (Figure 4.6) were expected, some others were not. It could even be argued that some of the results are not logical. Some of the reasons for these unexpected results could be associated with the assumptions described in the previous section. Another important reason is that alligator cracking, as available in PMIS, is highly variable and, to some extent, subjective. The percentage of alligator cracking reported in a PMIS section may depend on the operator collecting the data and the weather conditions at the time of data collection. Season (cold or hot), time of the day (morning, mid-day, afternoon), light (sunny or shady), and moisture (dry or after a rain episode) are all characteristics that may affect the number of cracks that an operator may see and report. For this reason, it is strongly recommended that cracking data (and in general, any type of pavement distress data) should be automatically collected to the maximum extent possible, hence, avoiding the subjectivity introduced by a human rater.

In addition to the analysis above, the rate of alligator cracking progression was also estimated for each of the 7,821 projects. Figure 4.7 shows the histogram of the distribution of the 7,821 slopes (rate of cracking progression) that were estimated. The positive slopes indicate that the percentage of alligator cracking increases with time, while negative slopes indicate that cracking decreases with time.

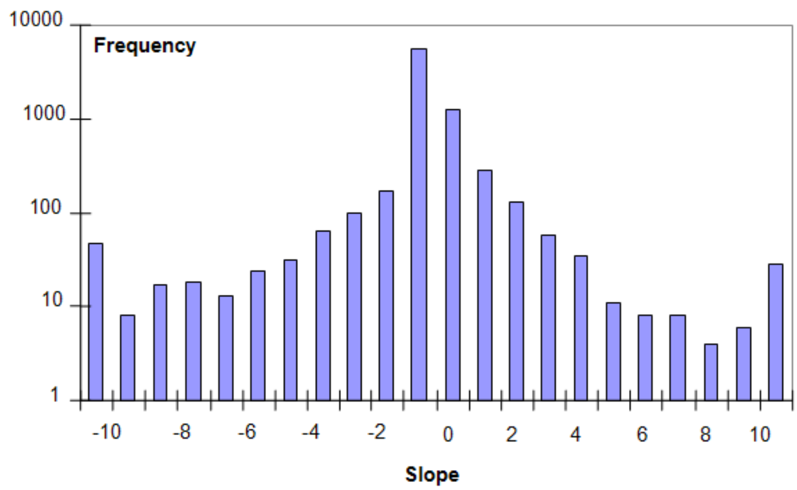


Figure 4.7: Rate of Alligator Cracking Progression (all projects)

The vast majority of the slopes represented in Figure 4.7 were found not to be statistically significant from zero, so additional filtering was done to eliminate not-significant slopes. As a result, it was found that only 1,455 sections had slopes statistically significant. Figure 4.8 shows the distribution of significant slopes only.

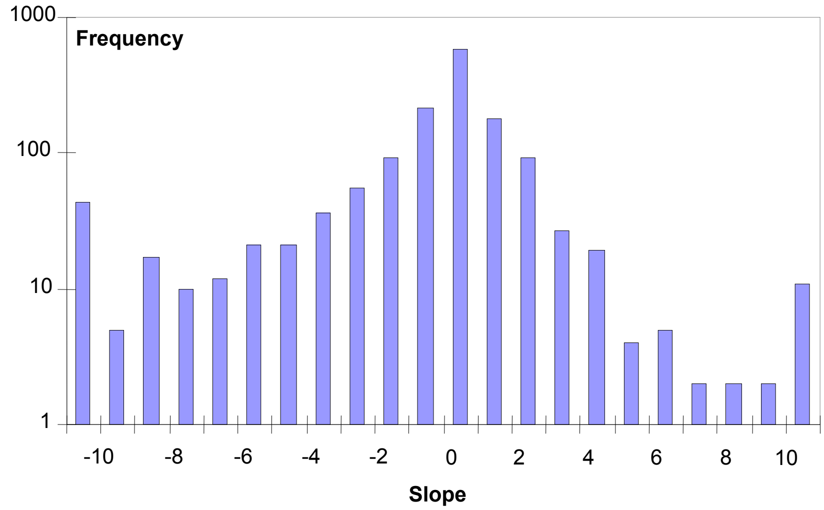


Figure 4.8: Rate Cracking Progression (only significant slopes)

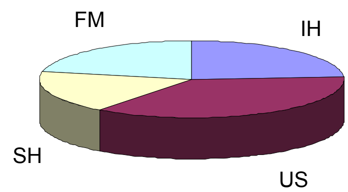
The analysis of the data from Figure 4.8 revealed that 63.8 percent of the slopes were positive while 36.2 were negative. However, these values should not be interpreted as project-specific tendencies but rather as the picture of the entire network. In other words, these statistics mean that cracking is going up in 63.8 percent of the projects and going down in the rest of the projects in the sample. The lack of information on project-specific maintenance activities makes it difficult to use the actual slope values as a measure of the cracking rate progression for specific projects (i.e., project-level).

4.3 Incorporation of SiteManager Data

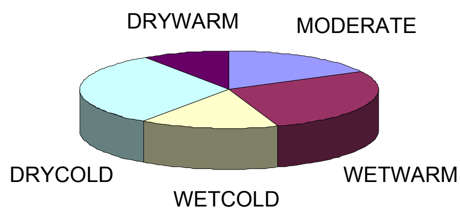
The third analysis reported in this chapter was based on the dataset that was created with the incorporation of SiteManager. With the incorporation of SiteManager, several advantages were realized immediately: (i) a much larger, more accurate and richer database in terms of material information, testing, and properties, and (ii) the ability to link three sources of information such as DCIS, PMIS, and SiteManager. Before the incorporation of SiteManager, the assumption had to be made that what was tendered was actually built. Thus, change orders or any other potential change between design and construction were not captured.

Unlike the analyses reported in the two previous sections, which were based on existing databases where location information of some type was available, the database for this analysis was completely developed as part of this research project. SiteManager contains CCSJ and descriptive information in terms of project location. This descriptive information was used to map the section and obtain its coordinates (latitude and longitude) using a GIS platform. This information was then used to link SiteManager to both DCIS (by means of CCSJ) and PMIS (by means of location).

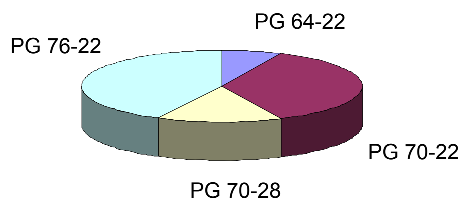
The results presented in this section were based on the analysis of the data for the first 150 Control-Section-Jobs (CSJs) of this new dataset. These correspond to the 150 longest projects available because they provide a larger database in terms of material properties and test results (SiteManager) and in terms of performance (PMIS). Figure 4.9 represents the distribution of these sections according to (a) highway system, (b) climate, (c) asphalt binder performance grade, and (d) mix type.



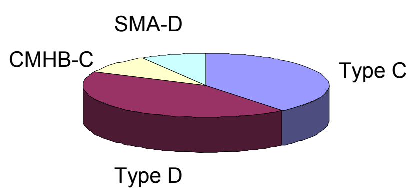
(a) by Highway System



(b) by Climate



(c) by Binder Performance Grade



(d) by Mixture Type

Figure 4.9: Distribution of Sections According to Main Characteristics

The 150 CSJs resulted in a total of 13,577 performance observations; however, these included data for pavement types outside the scope of this project and some projects with insufficient, incomplete or missing data. After cleansing the data, a total number of 8,182 performance observations were available for further analysis. The independent variables considered in this analysis were: (i) five environmental regions as before, (ii) four highway systems as before, and (iii) four mixture types, i.e., Type C, Type D, CMHB-C, and SMA-D. The reference case consisted of Type C mixes, FM highway system, and mixed or moderate environmental conditions.

The first analysis consisted of evaluating the effect of the variables on roughness in the left wheelpath. The summary results are presented in Figure 4.10 (a). Variables that were found not to be significant were highlighted (see Figure 4.10). For comparative purposes, an equivalent analysis of ride score data was also performed. The results of this analysis are shown in Figure 4.10 (b).

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	491452.6	49145.3	74.2	0.000
Residual	8172	5415616.3	662.7		
Total	8182	5907068.9			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	74.67	1.23	60.88	0.00
CMHBC	-4.38	1.26	-3.47	0.00
SMAD	-0.25	1.28	-0.20	0.84
TYD	-4.00	0.76	-5.28	0.00
IH	-10.89	1.07	-10.16	0.00
SH	-7.61	0.96	-7.92	0.00
US	-14.16	1.00	-14.20	0.00
DC	3.22	1.17	2.76	0.01
DW	-0.50	1.30	-0.38	0.70
WC	15.96	1.25	12.76	0.00
WW	-1.17	1.12	-1.05	0.29

(a) Left IRI

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	343.1	34.3	143.7	0.000
Residual	8172	1950.8	0.2		
Total	8182	2293.8			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	4.07	0.02	174.89	0.00
CMHBC	0.14	0.02	5.94	0.00
SMAD	-0.03	0.02	-1.22	0.22
TYD	0.09	0.01	5.92	0.00
IH	0.25	0.02	12.29	0.00
SH	0.22	0.02	12.27	0.00
US	0.42	0.02	22.00	0.00
DC	-0.12	0.02	-5.27	0.00
DW	0.02	0.02	0.93	0.35
WC	-0.39	0.02	-16.52	0.00
WW	0.04	0.02	1.75	0.08

(b) Ride Score

Figure 4.10: ANOVA Comparison of Left IRI and Ride Score

Despite the reduced number of projects used in this analysis, the sample size was slightly larger because longer sections were utilized. The first conclusion that could be drawn from the results shown in Figure 4.10 is that both models are very similar (in terms of their basic statistics), which indicates that the algorithm used to establish ride score relies heavily on roughness. In addition, some more specific conclusions could be drawn from the model. The first interesting result is that Type D mixes and CMHB-C mixes are better than Type C mixes in terms of roughness (or ride score). It can also be observed that the FM system is significantly rougher than the IH, US, and SH systems. Finally, on average, pavements in the dry-cold (DC) and wet-cold (WC) regions are rougher than those pavements in the other three environmental regions considered.

The effect of the variables on rutting was also evaluated. In this case deep rutting, as per PMIS definition, was used. The results of this analysis are presented in Figure 4.11. For the sections in the dataset, Type D mixes show significant more rutting than Type C mixes, while SMA-D mixes have better rutting resistance than Type C. IH, US, and SH highway systems show less rutting than the FM system. In general, mixes in the wet-cold, dry-cold, and dry-wet environments show more rutting than mixes in the Central Texas region; while mixes in the wet-warm environment show less rutting. Although this finding does not seem to be realistic, it should be noted that it is likely that mixes used in the wet-warm environment are more rutting resistant than those used elsewhere. Further statistical analyses including the effect of cross-terms should be carried out to address this question. However, as second order terms are incorporated into the analysis, more data is required to establish statistical significant results.

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	94.3	9.4	35.4	0.000
Residual	8172	2176.0	0.3		
Total	8182	2270.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.18	0.02	7.32	0.00
CMHBC	-0.03	0.03	-1.35	0.18
SMAD	-0.09	0.03	-3.33	0.00
TYD	0.07	0.02	4.79	0.00
IH	-0.06	0.02	-2.66	0.01
SH	-0.22	0.02	-11.22	0.00
US	-0.19	0.02	-9.46	0.00
DC	0.10	0.02	4.17	0.00
DW	0.09	0.03	3.34	0.00
WC	0.12	0.03	4.91	0.00
WW	-0.07	0.02	-3.35	0.00

Figure 4.11: ANOVA Effect of Various Properties on Deep Rutting

The last analyses reported in this section included the effects of the variables on alligator cracking and longitudinal cracking. The results of these analyses are presented in Figure 4.12 (a) and (b), respectively. In the case of alligator cracking (a distress associated with traffic loading) several of the variables are not significant (see highlighted variables in Figure 4.12 (a)). One of the most interesting findings is that SMA-D and CMHB-C mixes show significantly less alligator cracking than Type C mixes. In this case, the difference between Type C and Type D mixes is not significant. Dry-warm and wet-cold environments seem to have less alligator cracking than mixed (Central Texas). Overall the results are quite reasonable and promising. More significant and insightful results are expected as the dataset increases.

For the case of longitudinal cracking (a distress typically associated with environmental effects rather than traffic loading), Type D and Type C mixes do not seem to be significantly different; however, all other variables are (see Figure 4.12 (b)). As before, SMA-D and CMHB-C mixes are performing better than Type C mixes in terms of longitudinal cracking. Fewer longitudinal cracks are observed in Central Texas, while the most critical region is the dry-cold environment.

	df	SS	MS	F	Significance F
Regression	10	4112.8	411.3	12.1	0.000
Residual	8172	278407.5	34.1		
Total	8182	282520.4			

	Coefficients	Standard Error	t Stat	P-value
Intercept	1.98	0.28	7.12	0.00
CMHBC	-1.29	0.29	-4.51	0.00
SMAD	-1.86	0.29	-6.42	0.00
TYD	0.13	0.17	0.73	0.47
IH	0.14	0.24	0.59	0.55
SH	-0.57	0.22	-2.62	0.01
US	-0.18	0.23	-0.79	0.43
DC	-0.19	0.27	-0.70	0.48
DW	-1.06	0.29	-3.58	0.00
WC	-1.45	0.28	-5.12	0.00
WW	-0.31	0.25	-1.24	0.22

(a) Alligator Cracking

	df	SS	MS	F	Significance F
Regression	10	341071.0	34107.1	58.0	0.000
Residual	8172	4805616.6	588.1		
Total	8182	5146687.6			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-3.12	1.16	-2.70	0.01
CMHBC	-15.03	1.19	-12.64	0.00
SMAD	-4.69	1.20	-3.90	0.00
TYD	0.06	0.71	0.09	0.93
IH	10.88	1.01	10.78	0.00
SH	3.83	0.90	4.23	0.00
US	7.03	0.94	7.48	0.00
DC	14.05	1.10	12.75	0.00
DW	7.65	1.23	6.25	0.00
WC	3.75	1.18	3.18	0.00
WW	5.10	1.05	4.86	0.00

(b) Longitudinal Cracking

Figure 4.12: ANOVA Comparison of Alligator and Longitudinal Cracking

4.4 Summary of the Statistical Analyses

In this chapter, a series of statistical analyses were presented together with the corresponding results. The objective of this chapter was to present the types of analyses and conclusions that can be drawn from such analyses. The specific results presented herein, however, should be taken as provisional results only. The three analyses presented in the previous three sections correspond to the various stages of the study and the various datasets available at that time. Currently, a larger database is available online containing no less than 500 control section jobs (CSJs) with data from DCIS, PMIS, and SiteManager. The user is able to perform statistical analyses in real-time from the online application available at http://pavements.ce.utexas.edu/TxDB/TxDB.html. Since the databases will be constantly updated, these real-time analyses will produce the most updated results. Several aspects have the potential to significantly improve the accuracy of the analyses presented here. These aspects include: (a) a larger dataset, (b) information on maintenance and rehabilitation activities, (c) specific lane where PMIS data in collected, and (d) compulsory inclusion of location information in all TxDOT database, i.e., DCIS and SiteManager.

Chapter 5. Conclusions & Recommendations

The primary objective of the project was to develop a system to track the performance of HMA in Texas. The report outlines database and software developments done to achieve this goal. The developed system makes use of TxDOT databases including DCIS, PMIS, SiteManager, and GISTRM. The latter database consists of geographical coordinates of TRMs in Texas and was instrumental in establishing a link between SiteManager and PMIS. A web-based GIS software application was developed. This application provides a front-end with functions to (i) input new SiteManager projects into the system; (ii) filter, query, and edit existing projects; (iii) report general, performance, design, and construction information for SiteManager projects; and (iv) to statistically evaluate the influence of various factors, including HMA mixture type, on pavement performance. A mapping function is provided to identify the longitude and latitude coordinates of project beginning and ending extents.

The inclusion of the SiteManager database served to replace the use of DCIS. This was beneficial in that it facilitated the identification of asphalt mixtures used on TxDOT projects. Unfortunately, the project description and location information in SiteManager is lacking, and for this reason, the application as developed still makes use of the DCIS project table that provides more complete records. It is recommended that this shortcoming be addressed to eliminate the need for DCIS tables that would ease the maintenance of the application. It is further recommended that the application be given access to on-line TxDOT databases, such as the temporary or ad-hoc Sybase databases, generated daily from the TxDOT mainframe databases. This would eliminate the need to manually update the application databases and provide up-to-date information for queries and analyses.

The report outlines a number of shortcomings of the SiteManager QC/QA table used to track design and construction information for HMA mixtures. These relate mainly to problems experienced by the researchers to extract information from this table for querying purposes. It is recommended that this SiteManager table be revised to include data that has been validated and that the database include all HMA properties calculated from the current input fields. This would significantly improve the integrity of the data and the performance of database queries that currently require pre-validation and pre-calculation before data can be presented.

The report includes a series of statistical analyses that were presented together with the corresponding results to investigate the relative roughness, rutting, and cracking performance of various HMA mixtures, under varying conditions with respect to climate, traffic, pavement facility (structure), and amount of maintenance applied. While in general, the analysis results do positively indicate trends that are expected, others are unrealistic— the roughness measurements provided more realistic results compared to the cracking and rutting measurements. The incorporation of SiteManager allowed a better identification of project location and extents that addressed the shortcomings of using DCIS. As expected, this resulted in reduced errors associated with the analyses presented. Thus, while the analyses reported highlighted the potential benefits of a network-level analysis to track the performance of HMA in Texas, it also indicated some limitations with respect to the use of PMIS data, notably the insensitivity of the performance variables to PMIS rutting severity groupings and the subjective nature of PMIS visual assessments of cracking. The importance of identifying the first PMIS measurement on a section following its end-of-construction/rehabilitation date was emphasized together with the importance of tracking the maintenance done on a road section over its service life. While the latter was not a critical aspect for the SiteManager projects evaluated (constructed from 2004 onwards), it should be considered carefully as the SiteManager database grows over time.

The performance analysis results presented in this report are based on limited data available at the time. The application, however, includes a statistical analysis procedure that can be used to run real-time analysis of data, the volume of which is expected to grow over time as new SiteManager projects are added and the application databases are updated. A larger dataset will provide more robust analysis of mixture performance but will also allow performance analysis to be done at the district level— currently the limited number of SiteManager projects in the database limits analyses to performance of mixtures in Texas as a whole. This warrants the continued maintenance of the application databases as recommended previously.

Provision was made to expand the analysis to include factors such as binder performance grade and some HMA mixture related properties such as asphalt content, VMA, density, and lift thickness. Clearly there is the potential to improve the analysis procedure by incorporating additional influence factors and to expand the analysis procedure to allow cost-benefit calculations by incorporating cost information available in the SiteManager database.

The application provides a framework to track the performance of HMA in Texas. The link currently established between SiteManager and PMIS can be extended to link and include other TxDOT databases, e.g., the Texas Flexible Pavements database and the Maintenance Management Information System (MMIS) database. The application could be expanded and used to track the performance of other materials in Texas, not just HMA. It may be used to investigate the actual service lives of pavement systems in Texas. Furthermore, the geographical component of the application opens up numerous possibilities that may be explored to optimize construction operations. Clearly the current application only scratches the surface of what is now possible and it is strongly recommended that TxDOT continue the development of the application.

References

Hudson, W.R, Monismith, C.L., Dougan, C.E., and Visser (2002), W., Use of PMS Data For Performance Monitoring With Superpave As An Example, FHWA Contract DTFH61-98-C-00075, B98C75-007, Washington, D.C.

Smit, ADF (2005), Software and Database Developments to Track HMA Performance, Unpublished report submitted to the FHWA.

Appendix

The following is a listing of the SQL Query linking the SiteManager and PMIS database tables.

```
SELECT GEN_DB_PRJS.CONT_ID,GEN_DB_PRJS.PRJ_NBR,
GEN_DB_PRJS.LN_ITM_NBR,GEN_DB_PRJS.QTY,
GEN_DB_PRJS.PRICE,GEN_DB_PRJS.DISTRICT,
GEN_DB_PRJS.COUNTY,GEN_DB_PRJS.PJROUTE,
GEN_DB_PRJS.BTRM,GEN_DB_PRJS.ETRM,GEN_DB_PRJS.ISPECYR,
GEN_DB_PRJS.MIX,GEN_DB_PRJS.GRADE,GEN_DB_PRJS.FAC,
GEN_DB_PRJS.CLIMATE,GEN_DB_PRJS.DESAC,
GEN_DB_PRJS.FLDDENSITY,GEN_DB_PRJS.LABGMB,
GEN_DB_PRJS.VMA,GEN_DB_PRJS.HT,PMIS.FISCAL_YEAR,
PMIS.SIGNED_HIGHWAY_RDBD_ID,PMIS.BEG_REF_MARKER_NBR,
PMIS.BEG_REF_MARKER_DISP,PMIS.END_REF_MARKER_NBR,
PMIS.END_REF_MARKER_DISP,PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE,
PMIS.CURRENT_18KIP_MEAS,PMIS.AADT_CURRENT,
PMIS.SPEED_LIMIT_MAX,PMIS.NUMBER_THRU_LANES,
PMIS.VISUAL_LANE_CODE,PMIS.TOTL_SURF_RDWAY_WIDTH_MEAS,
PMIS.RURAL_URBAN_CODE, PMIS.SHOULDER_TYPE_RIGHT_CODE,
PMIS.SHOULDER_WIDTH_RIGHT_MEAS,PMIS.SHOULDER_TYPE_LEFT_CODE,
PMIS.SHOULDER_WIDTH_LEFT_MEAS,
PMIS.SECT_LENGTH_CENTERLINE_MEAS,PMIS.MAINTENANCE_COST_AMT,
PMIS.DISTRESS_SCORE,PMIS.CONDITION_SCORE,
PMIS.RIDE_SCORE,PMIS.LIRI,PMIS.RIRI,PMIS.AIRI,
PMIS.SKID_SCORE,PMIS.ACP_RUT_AUTO_SHALLOW_AVG_PCT,
PMIS.ACP_RUT_AUTO_DEEP_AVG_PCT,
PMIS.ACP_RUT_AUTO_SEVERE_AVG_PCT,
PMIS.ACP_RUT_AUTO_FAILURE_AVG_PCT,
PMIS.ACP_PATCHING_PCT,PMIS.ACP_FAILURE_QTY,
PMIS.ACP_BLOCK_CRACKING_PCT, PMIS.ACP_ALLIGATOR_CRACKING_PCT,
PMIS.ACP_LONGITUDE_CRACKING_PCT,
PMIS.ACP_TRANSVERSE_CRACKING_QTY, PMIS.ACP_RAVELING_CODE,
PMIS.ACP_FLUSHING_CODE
FROM PMIS INNER JOIN GEN_DB_PRJS ON
RTRIM(LEFT(PMIS.SIGNED_HIGHWAY_RDBD_ID,2) +
CAST(CAST(SUBSTRING(PMIS.SIGNED_HIGHWAY_RDBD_ID,3,4)
AS INT) AS VARCHAR(4))+
SUBSTRING(PMIS.SIGNED_HIGHWAY_RDBD_ID,7,1))=
GEN_DB_PRJS.PJROUTE AND
PMIS.FISCAL_YEAR >= GEN_DB_PRJS.PMISYR
WHERE
(CAST(LEFT(PMIS.BEG_REF_MARKER_NBR,4) AS FLOAT)+
PMIS.BEG_REF_MARKER_DISP >= GEN_DB_PRJS.BTRM) AND
(CAST(LEFT(PMIS.END_REF_MARKER_NBR, 4) AS FLOAT)+
PMIS.END_REF_MARKER_DISP <= GEN_DB_PRJS.ETRM) AND
(RIGHT(PMIS.SIGNED_HIGHWAY_RDBD_ID, 1) = 'K') AND
(GEN_DB_PRJS.LANE <> 3) AND
(PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'04' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'05' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'06' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'09') OR
```

```
(CAST(LEFT(PMIS.BEG_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.BEG_REF_MARKER_DISP <= GEN_DB_PRJS.BTRM) AND
(CAST(LEFT(PMIS.END_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.END_REF_MARKER_DISP >= GEN_DB_PRJS.ETRM) AND
(RIGHT(PMIS.SIGNED_HIGHWAY_RDBD_ID, 1) = 'K') AND
(GEN_DB_PRJS.LANE <> 3) AND
(PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'04' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'05' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'06' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'09') OR
(CAST(LEFT(PMIS.BEG_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.BEG_REF_MARKER_DISP >= GEN_DB_PRJS.BTRM) AND
(CAST(LEFT(PMIS.END_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.END_REF_MARKER_DISP <= GEN_DB_PRJS.ETRM) AND
(RIGHT(PMIS.SIGNED_HIGHWAY_RDBD_ID, 1) = 'L') AND
(GEN_DB_PRJS.LANE <> 3) AND
(PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'04' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'05' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'06' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'09') OR
(CAST(LEFT(PMIS.BEG_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.BEG_REF_MARKER_DISP <= GEN_DB_PRJS.BTRM) AND
(CAST(LEFT(PMIS.END_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.END_REF_MARKER_DISP >= GEN_DB_PRJS.ETRM) AND
(RIGHT(PMIS.SIGNED_HIGHWAY_RDBD_ID, 1) = 'L') AND
(GEN_DB_PRJS.LANE <> 3) AND
(PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'04' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'05' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'06' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'09') OR
(CAST(LEFT(PMIS.BEG_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.BEG_REF_MARKER_DISP >= GEN_DB_PRJS.BTRM) AND
(CAST(LEFT(PMIS.END_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.END_REF_MARKER_DISP <= GEN_DB_PRJS.ETRM) AND
(RIGHT(PMIS.SIGNED_HIGHWAY_RDBD_ID, 1) = 'X') AND
(GEN_DB_PRJS.LANE = 3) AND
(PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'04' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'05' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'06' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'09') OR
(CAST(LEFT(PMIS.BEG_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.BEG_REF_MARKER_DISP <= GEN_DB_PRJS.BTRM) AND
(CAST(LEFT(PMIS.END_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.END_REF_MARKER_DISP >= GEN_DB_PRJS.ETRM) AND
(RIGHT(PMIS.SIGNED_HIGHWAY_RDBD_ID, 1) = 'X') AND
(GEN_DB_PRJS.LANE = 3) AND
(PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'04' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'05' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'06' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'09') OR
(CAST(LEFT(PMIS.BEG_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.BEG_REF_MARKER_DISP >= GEN_DB_PRJS.BTRM) AND
(CAST(LEFT(PMIS.END_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.END_REF_MARKER_DISP <= GEN_DB_PRJS.ETRM) AND
```

```
(RIGHT(PMIS.SIGNED_HIGHWAY_RDBD_ID, 1) = 'R') AND
(GEN_DB_PRJS.LANE <> 3) AND
(PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'04' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'05' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'06' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'09') OR
(CAST(LEFT(PMIS.BEG_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.BEG_REF_MARKER_DISP <= GEN_DB_PRJS.BTRM) AND
(CAST(LEFT(PMIS.END_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.END_REF_MARKER_DISP >= GEN_DB_PRJS.ETRM) AND
(RIGHT(PMIS.SIGNED_HIGHWAY_RDBD_ID, 1) = 'R') AND
(GEN_DB_PRJS.LANE <> 3) AND
(PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'04' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'05' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'06' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'09') OR
(CAST(LEFT(PMIS.BEG_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.BEG_REF_MARKER_DISP >= GEN_DB_PRJS.BTRM) AND
(CAST(LEFT(PMIS.END_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.END_REF_MARKER_DISP <= GEN_DB_PRJS.ETRM) AND
(RIGHT(PMIS.SIGNED_HIGHWAY_RDBD_ID, 1) = 'A') AND
(GEN_DB_PRJS.LANE = 3) AND
(PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'04' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'05' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'06' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'09') OR
(CAST(LEFT(PMIS.BEG_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.BEG_REF_MARKER_DISP <= GEN_DB_PRJS.BTRM) AND
(CAST(LEFT(PMIS.END_REF_MARKER_NBR, 4) AS FLOAT) +
PMIS.END_REF_MARKER_DISP >= GEN_DB_PRJS.ETRM) AND
(RIGHT(PMIS.SIGNED_HIGHWAY_RDBD_ID, 1) = 'A') AND
(GEN_DB_PRJS.LANE = 3) AND
(PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'04' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'05' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'06' OR
PMIS.PVMNT_TYPE_DTL_RD_LIFE_CODE = N'09')
ORDER BY PMIS.FISCAL_YEAR
```