BRIDGING THE GAP BETWEEN NETWORK AND PROJECT SELECTION LEVELS IN PAVEMENT MANAGEMENT

A Thesis

by

CHARLES FELDER GURGANUS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Nasir G. Gharaibeh
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ABSTRACT

Bridging the Gap between Network and Project Selection Levels in Pavement Management. (May 2011)

Charles Felder Gurganus, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Nasir G. Gharaibeh

Pavement management is one of the primary responsibilities for departments of transportation and other municipalities across the country. Efficient and proper use of taxpayer dollars to preserve and improve the existing transportation system has never been more important due to the current fiscal environment. Agencies use pavement management systems to store data describing the state of the network. This information is often used to help make decisions regarding the location of pavement preservation actions. There is often a discrepancy between the need estimates of network-level pavement management systems and where and how pavement preservation and improvement dollars are actually spent (i.e., actual pavement preservation and improvement projects). This research focuses on evaluating the Texas Department of Transportation's (TxDOT) Pavement Management Information System (PMIS) to assess the agreement between its need estimates and actual construction projects at the district level. The research revealed there is little agreement between the output of PMIS's Needs Estimate tool and actual construction projects. Possible reasons for this disagreement include the inability of PMIS's Needs Estimates to consider the decision makers preferences and priorities, and its inability to consider multiple years of condition data simultaneously. Through the use of the Analytic Hierarchy Process (AHP), the research was able to capture the effect of several variables on the decision making process. Using this method, pavement project suggestions were created that more closely matched actual projects than what the current Needs Estimate tool suggests.

The projects selected using the new method were then tested against actual construction within three counties of the Bryan district. The new method closely matches actual preservation decisions made by the district within these three counties.

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Finally, I must thank my family for the sacrifices and support they have made during my time in school. I thank my son, Coleman, for understanding the amount of time I had to put into my work, for the times you had to tag along to class, and for always being so encouraging despite the situation. I thank my wife, Elizabeth, for pushing me in this endeavor, and I want you to know that without you none of this would have been possible. I can never thank you enough for everything you have done and sacrificed to make this possible for me.

NOMENCLATURE

ADT	Average Daily Traffic
AHP	Analytic Hierarchy Process
ARRA	American Recovery and Reinvestment Act
BRM	Beginning Reference Marker
CI	Consistency Index
Commission	Texas Transportation Commission
CR	Consistency Ratio
CS	Condition Score
DOT	Department of Transportation
DS	Distress Score
ERM	Ending Reference Marker
ESAL	Equivalent Single Axle Load
FHWA	Federal Highway Administration
FWD	Falling Weight Deflectometer
FY	Fiscal Year
GPR	Ground Penetrating Radar
HRhb	Heavy Rehabilitation
IRI	International Roughness Index
LRhb	Light Rehabilitation
M&R	Maintenance and Rehabilitation

MRhb	Medium Rehabilitation
NN	Needs Nothing
PM	Preventative Maintenance
PMIS	Pavement Management Information System
PMS	Pavement Management System
RI	Random Index/Random Consistency Index
RM	Reference Marker
RS	Ride Score
SPA	Seismic Pavement Analyzer
TxDOT	Texas Department of Transportation
UTP	Unified Transportation Program
VOC	Vehicle Operating Cost

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1. INTRODUCTION

1.1 BACKGROUND

The American Association of State Highway and Transportation Officials (AASHTO) guidelines for pavement management systems (PMSs) states that a pavement management system is "designed to provided objective information and useful data for analysis so that highway managers can make more consistent, cost-effective, and defensible decisions related to the preservation of a pavement network" (American Association of State Highway and Transportation Officials (AASHTO) 1990). Pavement management is performed at four hierarchical levels. These levels and their characteristics are summarized in Table 1.1 (Gharaibeh, unpublished lecture, 2010). Traditionally, pavement management systems are concerned with the lower three levels, network, project selection, and project levels (American Association of State Highway and Transportation Officials (AASHTO) 1990; Falls et al. 1994; Hudson et al. 1997; Smith 2002). The new emerging asset management paradigm is concerned with the top level, the strategic level (Falls et al. 1994; United States Department of Transportation Federal Highway Administration (FHWA) 2007).

This thesis follows the style of *Journal of Infrastructure Systems* (ASCE).

Table 1.1. Summary of Pavement Management Levels

Pavement Management Level	**Definition**	**Key Capabilities**	**Key Players**
Strategic	Analyzes investments and fund allocation across all agency owned assets	Can show impact of funding options and help justify the need for funds. Communicate these needs and impacts to funding authorities	Funding Authorities, Policy Makers, Senior Management
Network	Analyzes the needs and funding requirements for a specific asset within an agency	Perform needs analysis to determine what is required and how much it will cost. Also performs impact analysis to determine the effect of limited funds	Senior Management and Department Managers
Project Selection	Identifies constraints not considered at higher levels and refines possible alternatives in accordance with improved cost estimates	Selects specific areas for funding and further analysis for design.	Department managers
Project	Most detailed level where planning is complete and detail design and construction occurs	Able to consider local constraints and adapt to unforeseen issues at higher levels (usually field issues)	Engineers and Technical Staff

A key purpose of a network-level PMS is to identify pavement sections that need improvement, the types of improvement (preservation, major rehabilitation, or reconstruction), and the timing of the improvement, and to prioritize pavement preservation and renewal projects when funds are limited. These tasks are normally accomplished through two types of analysis (American Association of State Highway and Transportation Officials (AASHTO) 1990; Smith 2002; Haas et al. 1994):

- Needs analysis (no budget constraints): This analysis identifies preservation needs (when, where, and how) and amount of funds needed to complete these projects.
- Impact analysis: This analysis provides answers to various “what-if” questions regarding the effect of funding on the network condition.

Several analytical techniques exist to prioritize pavement preservation and renewal projects, including (Haas et al. 1994; Šelih et al. 2008; Guerre and Evans 2009;

Nuworsoo et al. 2006; Madanat 1993; Papagiannakis and Delwar 2001; Smith and Fallaha 1992; Straehl and Schintler 2004):

- Optimization (e.g., dynamic programming, integer programming, genetic algorithms)
- Incremental benefit-cost (IBC) analysis
- Ranking based on various parameters, such as pavement condition
- User-defined heuristic rules

Final project selection is normally made through negotiations among stake holders (e.g., engineers, managers, etc.), considering various engineering, socioeconomic, political, and practical factors, along with results from network-level analyses (i.e., needs analysis and impact analysis).

TxDOT currently employs the Pavement Management Information System (PMIS) as its PMS. PMIS is defined as "an automated system for storing, retrieving, analyzing and reporting information to help with pavement-related decision-making processes." It is PMIS that holds the score used by the Texas Transportation Commission (Commission) in the goal of having 90 percent of state pavements at "good or better" condition by fiscal year (FY) 2012. It is intended for PMIS to work both as a network level tool used by policy makers and funding allocators and as a project selection level tool used by TxDOT districts to monitor, select, and prioritize pavement needs (Texas Department of Transportation (TxDOT) 2009b).

Bridging the gap between network and project selection levels in PMSs (including TxDOT's PMIS) is paramount to making the best possible pavement related decisions. Thus, it is the decision making aspect of pavement management at the network-level and project selection level where this research will focus.

1.2 PROBLEM STATEMENT

A disconnect between the results of network-level analyses and project selection decisions (i.e., actual pavement preservation projects) can lead to loss of confidence in pavement management systems. Consequently, ad-hoc approaches to managing pavement networks may prevail. While an ad-hoc approach to selecting pavement preservation projects can be practical; it leaves highway agencies vulnerable to scrutiny about how effectively money is being spent and it makes defending project selection decisions difficult. This accountability is reinforced by the ever shrinking transportation budgets. Budget crisis is one of, if not the most, consistent themes in pavement management literature mentioned by United States Department of Transportation Federal Highway Administration (FHWA)(2007); Guerre and Evans (2009); Nuworsoo et al. (2006); Straehl and Schintler (2004); Álvarez et al. (2007); Pantha et al. (2010); Mahoney et al. (2010), just to name a few. Thus, it is critically important to assess the agreement between the results of network-level analyses and actual pavement preservation projects. And, to develop tools for bridging the gap between these levels of pavement management. This research addresses this issue for TxDOT's pavement management system.

TxDOT's PMIS holds vast amounts of pavement-related data (condition, traffic, distress density, etc.). The key is turning that data into information that can be used by decision makers at the strategic, network, and project level. TxDOT decision makers are not currently using the decision support tools within PMIS. PMIS is viewed merely as a database that is used as the statewide scorecard. The problem is that PMIS's Needs Analysis tool has never been evaluated or validated using actual pavement preservation projects. Thus, it is unknown whether the lack of using this decision-support tool is justified. The current opportunity is to enhance TxDOT's pavement preservation decision making process by evaluating tools and information currently available in PMIS and to develop an improved project selection and prioritization method. The new method must be systematic and account for important parameters considered when making pavement management decisions. This method should help TxDOT make more consistent decisions and in turn justify how taxpayer dollars are being spent.

1.3 RESEARCH OBJECTIVE

The goal of this research is to evaluate and improve PMIS as a tool that can help pavement managers make informed and cost effective decisions regarding pavement preservation project selection. The specific objectives of this research are:

1. Assess the agreement between pavement maintenance and rehabilitation actions recommended by PMIS's needs estimate tool (decision support arm of PMIS) and actual pavement preservation and improvement projects performed by TxDOT's districts.

2. Develop a decision support method for project selection that accounts for both quantitative and qualitative variables considered by pavement managers and district decision makers, using data that already exists in PMIS.
3. Validate the developed decision support method by evaluating a sample of pavement sections to create realistic preservation projects.

1.4 RESEARCH APPROACH

The following tasks have been performed to accomplish the objectives of this research study.

1.4.1 Task 1: Perform Literature Review

In order to properly perform this research study, it is critical to understand the current state of pavement management systems. Because a portion of this research focuses on TxDOT's PMIS, it is not only important to have understanding of state-of-the-art pavement management, but also knowledge of PMIS and it capabilities. This knowledge will be acquired through literature review. Furthermore, a study of asset management, decision analysis, and project selection literature will be performed. Additionally, particular focus will be paid to the analytic hierarchy process (AHP) and how it is used in decision making situations.

1.4.2 Task 2: Interview Districts to Determine How Decisions Regarding Current Pavement Preservation Actions are Made

Decision makers from the Bryan, Beaumont, Dallas, and Tyler districts were interviewed regarding current pavement preservation decisions. During the interview process, the decision makers were presented with a survey that contained possible input parameters used when making pavement preservation related decisions. The research will use information from these interviews and surveys when developing the project selection and prioritization method. By obtaining input from district decision makers, the researcher hopes to more accurately create a method that reflects the beliefs of district personnel.

1.4.3 Task 3: Assess Agreement between Actual Projects and PMIS Needs Estimate Recommendations

Construction data from the Bryan, Beaumont, and Dallas districts from FY 2007, 2008, and 2009 will be used to compare actual pavement preservation projects with pavement sections recommended by PMIS's needs estimate tool. Prior to developing a new method, it should be determined if the current tools in PMIS match actual construction practices. A method to determine if PMIS's recommendations agree with actual construction practices does not currently exist; therefore a method to test project agreement was developed. This comparison will also provide guidelines for how many years prior to construction data can and should be used to help make preservation decisions.

1.4.4 Task 4: Develop Improved Project Selection and Prioritization Method

The project selection and prioritization method will be built on the Analytical Hierarchy Process (AHP). This method has been chosen because of its ability to handle multi-criteria decision problems. This method is also successful in dealing with input parameters that are both qualitative and quantitative, thus making it attractive for transportation related decisions. The method focuses on aggregating parameters at the section level, just as PMIS does. The research then uses the information assigned to each section and analyzes multiple sections in an effort to create feasible pavement preservation projects.

1.4.5 Task 5: Test the Research Method Against Actual Construction Activities

The method developed must be vetted against actual construction activities to determine if the method has captured the parameters used in district decisions. By using input from district decision makers, it is believed that the method developed will more closely match reality. If reality is in fact correct, or is at least considered adequate in maintaining the current TxDOT system, a method should be developed that reinforcing current decision making practices. If the method is built upon district input and matches actual construction projects, it is plausible to believe with current information available, the system can generate decision possibilities that district decision makers agree with and support. This type of decision reinforcement can make the actions TxDOT takes more consistent and defensible in the eyes of the public, Commission, and legislators. There is also a brief discussion on the malleability of the method so that it can be modified with results from research or changes in policy or parameter priority. The researcher hopes to provide TxDOT with an effective decision support tool that can be used for preservation decisions immediately and can eventually be incorporated into a larger asset management plan.

1.5 THESIS ORGANIZATION

This thesis is described in five sections, described as follows:

- Section 1 provides background information regarding the research topic. This section also provides information regarding the problem statement, the research objective, research approach, and organization.
- Section 2 consists of literature review to provide the necessary background associated with current pavement management systems and the system used by TxDOT. A review of literature pertaining to project selection and prioritization is also included along with a review of infrastructure decision making literature, in particular the use of the analytic hierarchy process (AHP).
- Section 3 includes a summary of interviews with district decision makers and an analysis of actual pavement preservation projects against suggestions from the PMIS needs estimate. A method to determine if a preservation project has good agreement with the needs estimate is formulated. Within this agreement method, a point in history as to when data should be used to help make decisions is determined.
- Section 4 includes a discussion of the results from the TxDOT surveys that lead into the development of the new project selection and prioritization method based on the AHP technique. There is a thorough discussion on what variables are considered, how the variables are measured and weighted, and all components are aggregated to prioritize and select preservation projects.

Lastly, the projects suggested by the new method are tested against actual district construction history to ensure the method can mimic reality. As limitations are discovered in the method a discussion on how these should be addressed is included.

- Section 5 summarizes the thesis and offers concluding remarks. Recommendations for implementation of this research will also be given.

2. LITERATURE REVIEW

2.1 HISTORY AND PURPOSE OF PAVEMENT MANAGEMENT

June 29, 1956, not a date that is nearly as well-known as December 7, 1941 or September 11, 2001, and rightfully so, but for those in the roadway industry it is quite possibly the most significant day in the history of the industry, with President Dwight D. Eisenhower signing the Federal-Aid Highway Act of 1956 into law, initiating the construction of the nation's interstate highway system (Weingroff 2006). This is the beginning of massive capital investment in the nation's roadway transportation. This occurred more than 50 years ago and most agree that there has been a shift from investing in new capacity with capital construction to optimizing the current system and ensuring its integrity (United States Department of Transportation Federal Highway Administration (FHWA) 2007; Haas et al. 1994; El-Assaly et al. 2005). The need to optimize the highway system performance, considering limited resources, has led to the development of pavement management systems which have been used to help pavement managers make more informed and cost-effective decisions. While pavement management began with the Romans and the Appian Way, pavement management systems (PMS) are slightly newer with researchers beginning to use the term in the late 1960s (Haas et al. 1994).

Pavement management requires pavement engineers and decision makers to move beyond reactive maintenance practices and into the realm of decision making and asset management. To make this move, a pavement management system is needed to help system managers consider and weigh various parameters and data in a systematic manner. Accounting for the multiple components will help decision makers draw conclusions and select projects in a consistent and defensible way along with providing information on alternative strategies, how to optimize the use of limited funding, and provide feedback about decisions (Haas et al. 1994). The need to make consistent and defendable decisions has grown drastically in recent years as transportation decision makers are required to address system needs with shrinking budgets and limited resources. Legislative bodies are demanding more from highway agencies, such as TxDOT, in the way of efficiency, accountability, and transparency (Zimmerman et al. 2000).

While pavement management systems are data-driven, these systems should not be created to be simply databases of pavement related information. Instead, these systems should enable engineers to use and analyze this data to produce consistent decisions regarding project selection and prioritization (Haas et al. 1994; Shahin 1994).

There is a general agreement in the literature that pavement management systems should produce suggestions regarding preservation applications, these same sources and others also state that the pavement management system is only a tool and it is actually people who make the final decision (Haas et al. 1994; Madanat 1993; Li et al. 2006). For example, in Arizona, the pavement management system was overhauled to eliminate Markovian chain modeling that decision makers did not feel accurately represented project level decisions. The new system relies significantly on input from engineers, essentially making the suggestions from the system more human-driven (Li et al. 2006). Humans are decision makers, computer programs and management systems are only tools used to help humans make decisions.

In recent years, public and private highway agencies have begun to integrate their pavement management systems into broader transportation asset management programs to help perform strategic planning and prioritize funding across breadth of assets (bridges, drainage structures, roadside features, etc.) (Hudson et al. 1997; United States Department of Transportation Federal Highway Administration (FHWA) 2007; Vanier 2010). The evolution of these asset management programs typically begins in one asset area and many agencies use pavement management as the origin (United States Department of Transportation Federal Highway Administration (FHWA) 2007).

2.2 INTEGRATION OF PAVEMENT MANAGEMENT LEVELS

As discussed earlier (see Section 1.1 of this thesis), pavement management is generally performed at four hierarchical levels (strategic, network, project selection, and project). Haas et al. (1994) describe the network level as the phase where planning and prioritization occurs within budget constraints; while the project level is where the actual work comes "on stream." Haas et al. (1994) go on to divide the network level into two sub-levels: project selection and program. They specifically point out that in practice these levels are confused with each other. Regardless, it is clear that the levels must work together for the system to be effective.

Even with the knowledge that there are multiple levels within the decision making process and the desire to link these levels; the bridge between all levels has not yet been built. This disconnect between the results of network-level analyses and project selection decisions (i.e., actual construction projects) can be attributed to three main factors:

- Use of excessively detailed pavement management data
- Incompatibility between the lengths of pavement management sections and construction project
- Inability to consider routine reactive maintenance in network-level pavement management analyses
- Inability of network-level pavement management analyses to consider decision makers preferences and non-engineering factors

The first stumbling block between the levels stems from pavement management systems that have a plethora of data, but little in the way of useful information (United States Department of Transportation Federal Highway Administration (FHWA) 2007). It is often the excess data within these systems that lead to their demise and the continued use of the ad hoc approach to managing pavements (Smith and Fallaha 1992).

The second stumbling block between the levels is the fact that pavement management systems often use fixed pavement management sections (typically 0.5 mile long); whereas actual construction projects have no fixed length and can span over many pavement management sections. Making the transition from the section selection to the project selection has proved difficult and often causes discrepancies between network level planning and actual construction activities (Smith and Fallaha 1992). It is for this very reason that Arizona DOT rebuilt its pavement management system. The old system could not identify where work needed to occur, a major problem when trying to optimize pavement management across all levels (Li et al. 2006). A few research efforts have been made to combine consecutive pavement sections to create construction projects, with the understanding that at the project level continuity of work is required for efficiency and economics (Papagiannakis and Delwar 2001). Even when research is performed on existing management systems, in effort to make analysis results more closely match actual construction projects, success is not guaranteed. For example, the North Carolina Department of Transportation (NCDOT) attempted to use data mining and knowledge discovery techniques to uncover hidden information within the pavement management system that would help improve decision making. It was found that there remained discrepancies between what the program suggested and what decision makers would have implemented (Zhou et al. 2010).

The third cause of disconnect between network-level pavement management analyses and actual preservation projects is the inability to account for routine reactive maintenance. Most DOTs have some sort of in-house maintenance personnel that perform various functions, one of which is to reactively repair pavements to maintain an acceptable level. This work is very rarely accounted for in pavement management systems. It is not correct to call routine reactive maintenance a problem because in reality it serves an important function for the network, however in the realm of research it presents a variable that is not usually accounted for, mainly because it is difficult to quantify and predict when it will occur (Haas et al. 1994).

The fourth factor in network level and project selection level management failing to move in the same direction is the fact that pavement preservation and renewal projects are determined based on multi-criteria decisions. The network level optimization only looks at hard data and fails to realize that pavement-related decisions are made with both quantitative and qualitative inputs (Haas et al. 1994). This is discussed in more detail in Section 4 of this thesis, with application to TxDOT's pavement management system. While this information may not be comprehensive to allow for considering all necessary factors, it does offer a historical perspective of the pavement and is the only available information that can be implemented in a decision making method (Zhang et al. 2010).

2.3 OVERVIEW OF TXDOT PAVEMENT MANAGEMENT INFORMATION SYSTEM (PMIS)

TxDOT recognized the need to develop a pavement management system as early as 1971. Through research and implementation efforts beginning in 1971, the Pavement Evaluation System (PES) became a reality ten years later in 1981. The system provided information concerning the condition of the network in hopes of helping TxDOT monitor changes in the pavement network condition, eventually leading to support in securing funds and then evaluate the effectiveness of the use of these funds. This system focused on the network as a whole and offered little to no help in the realm of project level decision support. This changed with a complete overhaul of the system, predicated on the Federal Highway Administration (FHWA) mandate in 1989 that each State Highway Agency implements a pavement management system in compliance with the

AASHTO 1985 guidelines. By 1993, TxDOT implemented its PMS, supported by the automated Pavement Management Information System (PMIS) (Texas Department of Transportation (TxDOT) 1997).

PMIS stores and aggregates several pavement performance indicators including individual distress types, ride quality index, deflection measurements, and skid resistance measurements. Information concerning individual distress types is compiled from visual distress surveys performed by certified raters on all TxDOT mileage each year. Individual distresses are aggregated into overall scores (Distress Score and Condition Score) through mathematical algorithms. DS ranges from 1 to 100, increasing as distress decreases. Ride quality and rutting are measured less subjectively than distress. Measurements regarding these two performance indicators are obtained through a vehicle equipped with electronic profile and rut measuring devices. Using the ride measurement, PMIS calculates a Ride Score (RS) between 0.1 and 5.0 with 5.0 being a "very smooth" pavement. TxDOT states that if a section of pavement has a Ride Score below 3.0, the average person would consider it a rough ride. PMIS combines the DS and RS to create the Condition Score (CS) used to define a pavement's overall health. Table 2.1 lists the Condition Score classes used by TxDOT.

Table 2.1. TxDOT Condition Scores

Condition Score	Class	Description
90-100	A	Very Good
70-89	B	Good
50-69	C	Fair
35-49	D	Poor
1-34	F	Very Poor

While DS, RS, and CS are calculated for the entire TxDOT network, other information can be obtained on a more localized level. This information includes falling weight deflectometer (FWD) data, skid data, seismic pavement analyzer (SPA) data, or ground penetrating radar (GPR) data. There is currently no requirement to collect this data; therefore it is collected if individual districts requested the information.

PMIS scores are contained within formulas of the Unified Transportation Program (UTP) used to allocate funds across the State. The fact that PMIS scores are used by TxDOT's administration to distribute funds across Texas clearly illustrates the importance of PMIS as a network-level decision support tool. However, PMIS is needed to support not only network-level decisions; but also project selection decisions (Texas Department of Transportation (TxDOT) 2009c). To achieve this goal, it is important to understand the pavement management levels at TxDOT. These levels are illustrated in Figure 2.1.

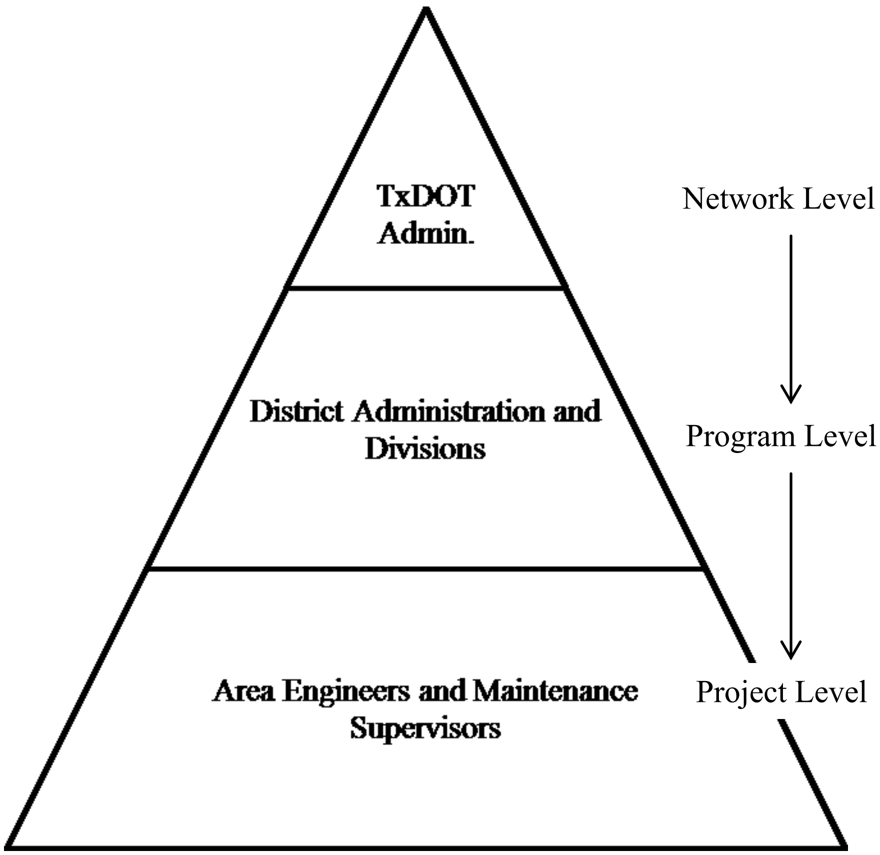


Figure 2.1. TxDOT Pavement Management Levels

Ultimately, TxDOT hopes that all three management levels can work cohesively to produce more cost-effective pavement preservation decisions. To bring decisions across all levels together, PMIS has the following three analysis procedures:

1. Needs Estimate
2. Projected Pavement Condition
3. Optimization and Impact Analysis

While predicting pavement performance and future condition is extremely valuable, this research focuses on preservation project prioritization and selection, through investigating the Needs Estimate tool. The Needs Estimate tool seeks to find sections within the network that require preservation treatments while the optimization tool seeks to use the treatments suggested by the needs estimate and prioritize what should be performed within a limited budget (Texas Department of Transportation (TxDOT) 2003).

The PMIS Needs Estimate tool searches the entire pavement network and locates sections that need a preservation action using pre-defined decision trees. Data regarding distresses and ride quality are evaluated in the Needs Estimate through a set of "if-then" statements that make up these decision trees. The Needs Estimate is a worst first tool in that it starts with the worst case scenario and moves through the decision tree until a statement is found to be true. When a true statement is found, it will correspond one of five broad M&R categories. These broad categories are:

1. Needs Nothing (NN)
2. Preventative Maintenance (PM)
3. Light Rehabilitation (LRhb)
4. Medium Rehabilitation (MRhb)
5. Heavy Rehabilitation or Reconstruction (HRhb)

Obviously from the categories above, there is a Needs Nothing category, indicating that the program has climbed all of the way down the decision tree and never found a true statement, implying no preservation work is required on the pavement section under consideration. The factors used to determine these preservation suggestions include, pavement type, distress ratings, Ride Score, ADT, number of lanes, functional class, county, date of last surface, 18-k ESAL, and section length (Texas Department of Transportation (TxDOT) 2009b).

Do the results of the Needs Estimate tool (i.e., pavement sections recommended for pavement preservation actions) agree with actual preservation projects selected by the districts, specifically in regard to preservation funds? If not, why and what improvements can be made to this tool to better match reality? What if reality needs to be modified in some ways to make more efficient and cost effective preservation decisions? This research investigates these questions and will offer possible solutions.

From previous research performed on this topic, it is known that five other states use decision trees to generate a preservation suggestion. These states are Montana, Nebraska, Nevada, New Hampshire, and Virginia. Other states use ratings and associated descriptions of rating levels to provide a general idea of what type of preservation action is required. Some are specific in terms of measure, such as Alabama which suggests an overlay at a score of 55 on its rating scale, but no further indication of what led to a score of 55 was provided. Others such as Illinois use the Pavement Condition Survey and provided the input that between a score of zero and 4.5, major rehabilitation is required immediately. West Virginia is another state that provides the general comment that rehabilitation is required when a pavement reaches a 2.5 on its rating scale that varies between one and five with five indicating a pavement in excellent condition. The components associated with each DOT’s measuring scale contribute to how the decision is made, however little information was available on moving from these general M&R actions viewed from a network level perspective to actual project selections (Papagiannakis et al. 2009)

To try and scope the impact of addressing these questions, it is important to discuss the cost of maintaining TxDOT's pavement network at adequate condition. TxDOT recently completed the 2010 Unified Transportation Program (UTP) which projects funding for FYs 2010-2020. Within the UTP, Category 1 is classified as Preventative Maintenance and Rehabilitation and constitutes the largest funding category. Table 2.2 illustrates the categories and projected dollar amount in the 2010 UTP.

Table 2.2. 2010-2020 Unified Transportation Program Categories and Projected Funding

Category #	Category Description	$ (Billions)
1	Preventative Maintenance and Rehabilitation	$10.71
2	Metropolitan Area (TMA) Corridor Projects	$1.97
3	Urban Area (Non-TMA) Corridor Projects	$0.28
4	Statewide Connectivity Corridor Projects	$0.07
5	Congestion Mitigation and Air Quality Improvement	$1.25
6	Structures Replacement and Rehabilitation	$2.81
7	Metropolitan Mobility and Rehabilitation	$2.11
8	Safety	$1.44
9	Transportation Enhancements	$0.68
10	Supplemental Transportation Projects	$0.82
11	District Discretionary	$0.73
12	Strategic Priority	$0.19
	Total	$23.05

While $10.71 billion seems significant over the next 11 years, the UTP states that there is a downward trend in state motor fuel tax receipts and additionally states that funding of other UTP categories is possible because the amount in Category 1 is lower than needed to maintain the system at its current level (Texas Department of Transportation (TxDOT) 2010). It should also be noted that the $10.71 billion is allocated throughout Texas to the 25 districts that comprise TxDOT. Districts then make decisions regarding how to spend this money. The current research does not focus on how this money is allocated to the various districts; rather it concedes that the allocation takes place for various reasons. It is however possible that with additional research the funding formulas used to allocate funds might be improved by considering an approach similar to that developed in this research effort. Regardless of any improvement in funding formulas, current and future pavement preservation decision making within TxDOT will likely take place at the district level where the specific needs of a regional constituency can be met. With this information, it is obvious that the need to wisely spend public funds on pavements is paramount not simply because the public and legislators demand it, but because funding is limited and continues to show a downward trend. Maximizing every penny will be crucial to the sustainment and betterment of the roadway system. In FY 2009, approximately 86 percent of Texas pavements were in "good or better" condition, four percent below the Commission mandate. In reality, the 90 percent goal has never been met (Texas Department of Transportation (TxDOT) 2009a). It is not merely the size of the system that is daunting, it is the funding situation.

2.4 DECISION MAKING

2.4.1 General Decision Making

From the evaluation of actual construction projects and preservation suggestions from PMIS (see Section 3.2 of this report), it is clear that reality does not perfectly match the current system used within TxDOT to help manage its pavement network. A fact that has been reported before as North Carolina Department of Transportation performed a study using data mining and knowledge discovery to extract hidden information from its pavement management system and run an algorithm to make preservation decisions. To test the algorithm, North Carolina Department of Transportation officials provided input on what treatment would have been selected. On several pavement sections, the program did not coincide with what decision makers would have done (Zhou et al. 2010). For this research, the interviews with district decision makers shine some light on why PMIS-suggested treatments and actual pavement preservation projects do not match, but several questions remain to be addressed.

Why is project selection important? The easy answer is funding. While it is true that if there was an endless supply of money, project selection would be much less of an issue, funding is not the entire answer. The remainder of the answer lies in the fact that most infrastructure systems, roadways included, require a certain amount of maintenance to reach or exceed its service life. Funding, or lack thereof, implies that the entire system cannot be worked on all of the time; therefore projects must be selected in such a way that the pavement can be improved by a preservation action. Literature is rich with the statement that making incorrect decisions about where and what preservation treatment to apply or prolonging an action when it could have been performed increases the total cost of the asset over its lifecycle (Hudson et al. 1997; Šelih et al. 2008; Madanat 1993; Papagiannakis and Delwar 2001; Pantha et al. 2010; Obaidat and Al-kheder 2006). Therefore, even if funding were limitless, it makes no logical sense to work on anything and everything without a structured approach to help make decisions when poor decisions can actually lead to higher life-cycle costs. If project selection is important, should there be a method to select projects that matches reality or at least should there be correspondence between management systems and actual decisions? From Section 2, it is clear that not only should pavement management systems have this capability, but TxDOT's PMIS has tools specifically designed within it to perform these tasks.

Unfortunately, project selection is not the only issue that must be reconciled. Because limited funding is a reality, it is not enough to simply find where work needs to occur, projects must be prioritized. Fiscal limitations are not the only factor that force pavement managers to prioritize projects, there are more demands on the system and other resources such as material and labor are becoming more expensive (Nuworsoo et al. 2006; Straehl and Schintler 2004; Álvarez et al. 2007; Pantha et al. 2010). To allocate resources more effectively and spend money more wisely, transportation decision makers have to select the option that provides the most benefit from many competing projects.

Long gone are the days of simply building new roads and new lanes to solve transportation problems. There has been a shift from capital construction to maintenance and preservation of the existing system (United States Department of Transportation Federal Highway Administration (FHWA) 2007). Mahoney suggests that Washington State requires $7000/lane mile/year to preserve the investment in the original system. This number is all inclusive, consisting of not just construction, but also engineering and construction inspection (Mahoney et al. 2010). If that lane mile cost were applied to Texas, with just under 195,000 lane miles, the yearly preservation cost would be approximately $1.37 billion dollars. If the dollar amount is so large and it appears obvious that project selection and prioritization is needed, why isn't it readily available in industry? Even TxDOT's PMIS program has tools created that should help with managing pavements in more of an asset management style, but they are not being used. What problems need to be overcome to manage pavements better?

One of the stumbling blocks is the multiple variables that must be considered when making decisions about pavements. Maybe it is merely the empirical nature of transportation or dealing with the traveling public, but making decisions about which transportation and more specifically pavement projects to pursue is not as simple as selecting the roadway with the worst distress and going out and fixing it. Other factors such as traffic volume, number of trucks, location, number of lanes, regional development, and even political pressure plays a part in where pavement preservation work is conducted. For example, a study was performed on how to prioritize roadway maintenance projects in the Himalayan Mountains of Nepal which used slope stability as one of its key decision making variables. It was paramount that this parameter was included because a landslide could mean closing a road for weeks at a time and in the mountainous area there is typically very few ways in and out (Pantha et al. 2010). While possible rock slides might not be one of the input parameters to TxDOT's decision-making process, the Houston and Beaumont districts might want to include evacuation route as a parameter to consider when determining how and where to spend pavement preservation funds. This research investigates the use of the Analytic Hierarchy Process (AHP) as a way to deal with the multiple criteria considered in pavement project selection decisions.

2.4.2 Analytic Hierarchy Process (AHP)

What is the AHP and why use it? The AHP is a multi-criteria decision making method that finds its origins in the early 1970s as its creator was working on contingency planning for the Department of Defense (Saaty 1980). Its development stemmed from the need to organize and make decisions dealing with unstructured problems. Not only were the problems unstructured, but the components within these problems had no unit or measure or several different units of measure. The creator of the method sought to overcome this issue through the creation of hierarchy that could be broken down into levels. The elements on these levels could be placed a pairwise matrix where each element could be compared against the other element. The goal and stated achievement is that the method mimics how people actually think and decide (Saaty 1990b). Comparing components to one another creates a matrix based on a ratio scale that must utilize matrix calculations to arrive at weights for the various competing decision criteria. While the AHP has been modified in other work and expanded since its inception, this research uses the eigenvector approach just as the creator of the method originally suggested. Weights are created from the method by calculating the maximum eigenvector for pairwise matrix and then normalizing that vector so that the weights will sum to one. The maximum eigenvalue is used to test for consistency of judgments, an important point because the AHP relies on consistent judgments by it participants (Saaty 1990a).

This research does not seek to validate the AHP, rather it assumes the AHP is a credible decision making method and seeks to apply it to the project selection decision making problem in pavement management. The assumption of credibility is based on the evolution of the AHP over 40 years and its expansion into multiple sectors of decision making. In fact it has become one of the most widely used multi-criteria decision making tools finding it ways into the manufacturing, engineering, industrial, governmental, and political sectors, just to name a few. The method has evolved to the point that in 2006 an article was published devoted to a review of the applications of the AHP (Vaidya and Kumar 2006). Literature also states that confidence has grown in the method as decisions have been made across a diverse group of situations that are currently accepted and used in industry (Forman and Gass 2001).

Sinha et al. (2009) applied the AHP to establish weights of performance criteria for transportation systems. Sinha et al. (2009) tries to overcome the fact that single-criteria decision making assumes one parameter is so much more important than all other parameters that the decision can be based on that one thing and this type of mentality cannot be used in transportation decision making. The goal is to make a decision that gives consideration to all inputs necessary to achieve the highest level of desirability for the managing agency and its customers.

Al-Barqawi and Zayed (2008) use the AHP to create a decision making tool for water mains. This method was chosen because the authors believe it simulates the human decision process. Interestingly, water main decisions include many variables, some of which are considered in pavement projects. Examples include material type, location, and operation.

Farhan and Fwa (2009) used the AHP to prioritize pavement maintenance needs. The authors choose the AHP because of its ability to measure quantitative and qualitative variables. This is better than using a single index or composite number because it will not mask the contributions of the various input parameters. Farhan and Fwa (2009) stated that the AHP method has less variation than the direct weighting method to which it was compared, an important point when legislators and the public are demanding consistency and accountability from highway agencies such as TxDOT.

Šelih et al. (2008) and Khademi and Sheikholeslami (2010) each use the AHP to develop weights for the different criteria used in highway decision making. Each uses the AHP to establish priorities and do so because of the method's ability to capture the relative importance of each variable. Al-Harbi (2001) used the AHP to help solve the problem of contractor prequalification. This problem presents a quandary to project owners as effort is made to eliminate unqualified contractors from the bidding process. It is difficult to determine how the relationships associated with the various criteria relate and many have struggled with not only the relation of components, but how should the components be weighted. All of these issues were addressed using the AHP (Al-Harbi 2001).

Korpela and Tuominen (1996) used AHP for selecting the optimum site for warehouse placement. The authors mentioned the need to choose wisely based on economic and competitive advantages that can be achieved by having a warehouse in the proper location. This is an interesting parallel to pavement preservation project selection because this article is published in an economics journal, but it illustrates the need for structured decision making.

Zhang et al. (2001) have used AHP to help prioritize pavement data collection efforts for TxDOT. This study was done to isolate and weight data that is needed in PMIS. This is performed from a collection and policy standpoint, not a project decision support perspective (Zhang et al. 2004).

A recent study, Sun and Gu (2010), has been performed that focuses on pavement condition and the prioritization of pavement projects. Similar to the parameters captured by Sun and Gu, their study speaks of the importance of the road when determining where funds should be spent. The definition of this importance is made up of several parameters that the author uses the AHP to comparatively weight. This author focuses on different parameters included in pavement condition and seeks to make the optimum decision by appropriately aggregating this parameter, while at the same time mentioning that in practice other components are also included and must be accounted for in project prioritization. This study also only focuses on the prioritization of eight roadway sections while mentioning that an actual pavement network will contain tens of hundreds of segments (Sun and Gu 2010). That article is most similar in application of the AHP to the current research; however this research makes efforts to capture more than pavement condition and seeks to apply the AHP to a real network consisting of thousands of sections.

3. AGREEMENT BETWEEN PMIS OUTPUT AND ACTUAL CONSTRUCTION PROJECTS

3.1 TXDOT's PAVEMENT MANAGEMENT DECISION MAKING PROCESS AT THE DISTRICT LEVEL

In an effort to better understand current TxDOT decision making at the district level, interviews were conducted with decision makers from the Bryan, Beaumont, Dallas, and Tyler districts. The interviews focused on current methods and how PMIS and tools within PMIS were used for decision support. During these interviews, decision makers were also presented with surveys containing 25 parameters that might be considered when making pavement preservation decisions. The decision makers were asked to rank these parameters from very low, low, medium, high, and very high when considering whether or not a pavement section required preservation work and when considering what type of preservation work might be required. The questions used in the interviews are listed below:

- Please describe how the District currently selects roadways for a construction project using Category 1 money (pavement preservation and rehabilitation).
- Please describe how the District currently selects the type of treatment (or work action) that is applied to the projects identified from question 1.
- Does the District have a formal definition of the following work actions? If yes, what is that definition?

- If the answer to the question above is yes, does the District have a $/mi defined for each type of work action?
- How is routine maintenance money competed for between the different maintenance sections within the District?
- Does your District use in-house (routine maintenance) forces to prepare roadways for construction projects? If yes, how?
- How, if at all, does the District use PMIS when determining which roadways need pavement work?
- How, if at all, does the District use PMIS when selecting a type of work to be performed on a section of roadway?
- How confident are you in PMIS's optimization tool?

Information gleaned from these interviews helped explain discrepancies between preservation actions recommended by TxDOT's pavement management system and actual construction projects. Also, this information is used in the development of the new method for preservation project selection and prioritization (Section 4).

Conversations regarding pavement preservation began with a discussion of the district wide seal coat program. Each district's program may be slightly different, but the funding necessary for the district wide seal coat program is removed from the budget first and then other preservation actions are considered. Appendix A contains a more detailed discussion of each district's seal coat program. After allocating Category 1 funds for the district wide seal coat program, attention is turned to additional preservation projects. In regards to how PMIS is used in the preservation project selection process, three of the four districts interviewed use it as a "decision check" tool. Essentially, districts ensure that roadways with a CS under 70 are having some type of preservation action performed either by contract or through in-house work. The development of a project list within these three districts initiates from visual observation of actual pavement condition. During the interview process, many decision makers expressed concerns that PMIS evaluations are performed and the scores built based on distresses present, but the distresses that make up the score are often addressed by maintenance forces or a construction project looms that will repair the pavement problem.

In summary, decision makers see PMIS as a repository of pavement condition data at one epoch in time. It contains significant information primarily used to paint a picture of TxDOT's roadways that can be provided to the Commission. It offers little in the way of helping make decisions regarding project selection or prioritization. A more thorough summary of the district interviews is located in Appendix B.

3.2 PROJECT AGREEMENT ANALYSIS

This analysis seeks to assess the agreement between output of PMIS Needs Estimate tool (i.e., recommended maintenance, rehabilitation, and re-construction actions for pavement sections) and district construction project selection decisions. To perform this analysis, Category 1 construction letting from FY 2007, 2008, and 2009 from Beaumont, Bryan and Dallas districts was obtained. With this information, the needs estimate for the pavement sections within the project limits can be created. The Needs Estimate can be generated for the FY immediately prior to the construction letting or for multiple years prior to construction. If the Needs Estimate tool currently matches district decisions, the tool will be validated and it will be more necessary to educate district decision makers regarding the tool rather than generate another method. Otherwise, the Needs Estimate tool will need an improved method for project selection and prioritization.

3.2.1 Project Agreement Analysis for Bryan District

Table 3.1 illustrates the construction from FY 2007 compared with the Needs Estimate from FY 2006.

Table 3.1 indicates that 629 sections received some type of preservation action from a construction project let in FY 2007. Of these sections, approximately 42 percent had Needs Nothing (NN) suggestions generated by the FY 2006 Needs Estimate. The obvious question is why would TxDOT repair or improve pavement sections that its own management system indicates require no repair or improvement? The answer to this is twofold. First, a proactive pavement management program will inevitably result in spending money where a problem has not yet manifested to ensure that the system remains at or above an acceptable level. This is especially true with the seal coat program throughout Texas. Second, TxDOT lets construction projects, not construction sections. PMIS provides information on pavement sections, usually a ½-mile in length, and then aggregates those sections to create information about the network. Category 1 projects often span several miles and therefore multiple sections within PMIS. From the district level standpoint, it is important to work in terms of projects, not just sections.

Bridging the gap between network-level (section) and project-level is where new decision making tools are needed to help pavement managers.

Table 3.1 continues the illustration of the FY 2006 needs estimate preservation suggestions with a more detailed evaluation of FY 2007 projects. The lengths shown in Table 3.2 are approximate and are based on the average section length corresponding to the project length provided in the contract description and the number of sections affected according to PMIS. This approximation results in sections lengths of approximately 0.48-mile, an expected result because most of the sections within PMIS are ½-mile in length. Tables 3.2 and 3.3 provide similar information for FY 2008 and FY 2009 construction.

For FY 2007 construction (Table 3.1), the 65 projects consisted of 56 seal coat projects, 3 restoration projects, and 6 grading/structures/base/surface projects, spread over 629 sections, 262 of which received an NN suggestions from the needs estimate. Of the 262 NN sections, 257 were part of seal coat projects. Seal coat projects often contain a significant number of NN sections. In FY 2008 there were 319 NN sections receiving a seal coat, there were only 345 NN sections that received any sort of preservation work. The trend continues for FY 2009 construction where 249 NN sections received a preservation action, 219 of these received a seal coat.

Table 3.1. 2007 Construction Project Description and Needs Estimate Suggestions (Bryan)

Project Type	# of Projects		NN	PM	LRhb	MRhb	HRhb	Total
Seal Coat	56	Length (mi)	120.8	76.6	38.5	18.3	0.5	254.7
		# of Sections	257	163	82	39	1	542
Overlay	0	Length (mi)						
		# of Sections						
Rehab	0	Length (mi)						
		# of Sections						
Restore	3	Length (mi)	0.5	5.0	3.0	6.0	3.5	17.9
		# of Sections	1	10	6	12	7	36
Grading/Structure/ Base/Surf	6	Length (mi)	2.0	12.2	5.9	4.9	0.0	24.9
		# of Sections	4	25	12	10	0	51
Plane & Overlay	0	Length (mi)						
		# of Sections						
Totals	**65**	**Length (mi)**	**123.2**	**93.8**	**47.4**	**29.2**	**3.9**	**297.5**
		% of Length	**41%**	**32%**	**16%**	**10%**	**1%**	
		# of Sections	**262**	**198**	**100**	**61**	**8**	**629**
		% of Sect.	**42%**	**31%**	**16%**	**10%**	**1%**	

NN = Needs Nothing
PM = Preventative Maintenance
LRhb = Light Rehabilitation
MRhb = Medium Rehabilitation
HRhb = Heavy Rehabilitation

Table 3.2. 2008 Construction Project Description and Needs Estimate Suggestions (Bryan)

Project Type	# of Projects		NN	PM	LRhb	MRhb	HRhb	Total
Seal Coat	38	Length (mi)	149.9	32.0	12.2	5.6	0.5	200.2
		# of Sections	319	68	26	12	1	426
Overlay	0	Length (mi)						
		# of Sections						
Rehab	0	Length (mi)						
		# of Sections						
Restore	0	Length (mi)						
		# of Sections						
Grading/Structure/ Base/Surf	4	Length (mi)	11.7	5.4	1.5	1.5	0.0	20.0
		# of Sections	24	11	3	3	0	41
Plane & Overlay	3	Length (mi)	0.4	19.3	0.0	0.0	0.0	19.7
		# of Sections	2	90	0	0	0	92
Totals	**45**	**Length (mi)**	**162.1**	**56.6**	**13.7**	**7.1**	**0.5**	**240.0**
		% of Length	**68%**	**24%**	**6%**	**3%**	**0%**	
		# of Sections	**345**	**169**	**29**	**15**	**1**	**559**
		% of Sections	**62%**	**30%**	**5%**	**3%**	**0%**	

NN = Needs Nothing
PM = Preventative Maintenance
LRhb = Light Rehabilitation
MRhb = Medium Rehabilitation
HRhb = Heavy Rehabilitation

Table 3.3. 2009 Construction Project Description and Needs Estimate Suggestions (Bryan)

Project Type	# of Projects		NN	PM	LRhb	MRhb	HRhb	Total
Seal Coat	46	Length (mi)	102.9	126.0	13.6	8.5	1.9	252.9
		# of Sections	219	268	29	18	4	538
Overlay	4	Length (mi)	4.3	0.5	0.5	0.3	3.7	9.3
		# of Sections	16	2	2	1	14	35
Rehab	3	Length (mi)	2.9	4.9	0.4	0.4	0.0	8.7
		# of Sections	13	22	2	2	0	39
Restore	3	Length (mi)	0.5	6.2	9.9	4.7	0.0	21.3
		# of Sections	1	12	19	9	0	41
Grading/Structure/ Base/Surf	4	Length (mi)	0.0	2.5	8.0	12.5	3.0	26.0
		# of Sections	0	5	16	25	6	52
Plane & Overlay	0	Length (mi)						0
		# of Sections						0
Totals	**60**	**Length (mi)**	**110.6**	**140.1**	**32.5**	**26.4**	**8.6**	**318.2**
		% of Length	**35%**	**44%**	**10%**	**8%**	**3%**	
		# of Sections	**249**	**309**	**68**	**55**	**24**	**705**
		% of Sections	**35%**	**44%**	**10%**	**8%**	**3%**	

NN = Needs Nothing
PM = Preventative Maintenance
LRhb = Light Rehabilitation
MRhb = Medium Rehabilitation
HRhb = Heavy Rehabilitation

Through an interview with Bryan district personnel, it was discovered that Bryan has tried to develop a seal coat cycle by using the previous 10 years' seal coat plans, thus helping to explain why and how this occurred. Seal coat projects will not be evaluated further for project agreement in the Bryan district; instead the analysis will focus on heavier preservation treatments. The obvious question with the exclusion of seal coat projects becomes, does the needs estimate agree with construction projects of a heavier type? The answer is, not always. Table 3.4 shows preservation types suggested by the

Needs Estimates tool for the pavement sections within the boundaries of three grading/structure/base/surface projects from 2008 construction. The PMIS versus actual projects agreement statistics are shown in Table 3.5.

Table 3.4. Needs Estimate for 2008 Construction Projects FM 39, SH 7, and US 190

HWY	BRM	ERM	Reason Code	Preserv. Suggested by PMIS
FM0039	0388 +01.0	0388 +01.5	A999	NN
FM0039	0388 +01.5	0390 +00.0	A999	NN
FM0039	0390 +00.0	0390 +00.5	A999	NN
FM0039	0390 +00.5	0390 +01.0	A999	NN
FM0039	0390 +01.0	0390 +01.5	A999	NN
FM0039	0390 +01.5	0392 +00.0	A999	NN
FM0039	0392 +00.0	0392 +00.5	A999	NN
FM0039	0392 +00.5	0392 +01.0	A999	NN
FM0039	0392 +01.0	0392 +01.5	A105	MRhb
FM0039	0392 +01.5	0394 +00.0	A999	NN
FM0039	0394 +00.0	0394 +00.5	A999	NN
FM0039	0394 +00.5	0394 +01.0	A999	NN
FM0039	0394 +01.0	0394 +01.5	A105	MRhb
FM0039	0394 +01.5	0396 +00.0	A610	PM
FM0039	0396 +00.0	0396 +00.5	A999	NN
FM0039	0396 +00.5	0396 +01.0	A705	PM
FM0039	0396 +01.0	0396 +01.5	A999	NN
FM0039	0396 +01.5	0396 +02.0	A999	NN
SH0007	0624 +00.0	0624 +00.5	A999	NN
SH0007	0624 +00.5	0624 +01.0	A999	NN
SH0007	0624 +01.0	0624 +01.5	A615	PM
US0190	0744 +00.0	0744 +00.5	A999	NN
US0190	0744 +00.5	0744 +01.0	A999	NN
US0190	0744 +01.0	0744 +01.5	A999	NN
US0190	0744 +01.5	0746 +00.0	A520	PM
US0190	0746 +00.0	0746 +00.5	A999	NN
US0190	0746 +00.5	0746 +01.0	A999	NN
US0190	0746 +01.0	0746 +01.5	A520	PM
US0190	0746 +01.5	0748 +00.0	A520	PM
US0190	0748 +00.0	0748 +00.5	A999	NN
US0190	0748 +00.5	0748 +01.0	A520	PM
US0190	0748 +01.0	0748 +01.5	A999	NN

Table 3.5. FM 39, SH 7, & US 190 Construction Summary

Project HWY	Cost ($, million)		NN	PM	LRhb	MRhb	HRhb	Total
FM 39	3.4	Length (mi)	7	1	0	1	0	9
		# of Sections	14	2	0	2	0	18
		% in Length	78%	11%	0%	11%	0%	100%
SH 7	1.2	Length (mi)	1	0.5	0	0	0	1.5
		# of Sections	2	1	0	0	0	3
		% in Length	67%	33%	0%	0%	0%	100%
US 190	0.47	Length (mi)	3.5	2	0	0	0	5.5
		# of Sections	7	4	0	0	0	11
		% in Length	64%	36%	0%	0%	0%	100%

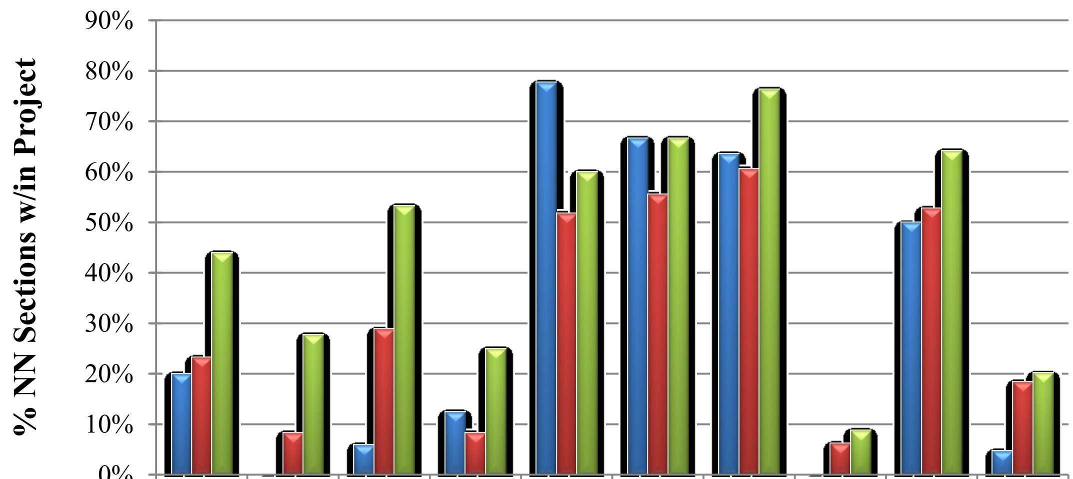
The question becomes why a $3.4 million project has almost 80% of its sections as Needs Nothing? One answer includes, the Needs Estimate tool does not accurately estimate preservation needs; or maintenance has been performed within the project limits that is represented in the Needs Estimate suggestions, while in reality the root of the problem has not been corrected. Based on the district interviews, it was determined that the Needs Estimate tool in PMIS does not completely account for all factors that the decision makers consider when making pavement preservation decisions. The lack of agreement between actual decisions and the Needs Estimate tool highlights the need to investigate improvements to decision support tools available to TxDOT.

TxDOT districts are broken into area offices and within area offices there are maintenance sections. Each of these sections has employees that perform various maintenance activities throughout their respective section. Some of these maintenance activities include pavement repair to keep the pavement in a condition acceptable to the general public. This type of maintenance could affect the information in PMIS and cause the needs estimate to change. It is hypothesized that only looking one-year prior to construction could discount routine maintenance and mask a larger problem that needs attention. For that reason, before continuing the analysis, the researcher generated needs estimates for as far back as five years prior to construction. With this information it is assumed that routine maintenance will be accounted for and the true problem spots will rise to the top, so to speak. Table 3.6 summarizes 10 construction projects completed in the Bryan district in FY 2007, 2008, and 2009.

Table 3.6. Bryan District Construction Projects in FY 2007-2009

HWY	Cosnt. FY	BRM	ERM	CSJ	Const. Cost	Length (mi)	Work Description
FM 60	2007	0608 +00.0	0614 - 01.3	0713-01-030	$1,870,333.00	4.3	Grading/Struc/Base/Surf
FM0485	2007	0604 +00.0	0610 +00.0	0262-03-027	$489,895.00	5.9	Restore
US0084	2007	0750 +00.5	0758 +00.0	0057-04-022	$3,825,480.00	7.4	Grading/Struc/Base/Surf
FM0039	2008	0388 +01.0	0396 +02.0	0643-01-049	$3,423,978.00	9.0	Grading/Struc/Base/Surf
FM2562	2008	0414 +00.0	0418 +00.0	3302-01-013	$1,443,326.00	4.0	Grading/Struc/Base/Surf
SH0007	2008	0624 +00.0	0624 +01.5	0335-03-040	$1,216,072.00	1.5	Grading/Struc/Base/Surf
US0190	2008	0744 +00.0	0748 +01.5	0213-01-037	$4,725,502.00	5.5	Grading/Struc/Base/Surf
FM0080	2009	0354 - 00.3	0360 +01.5	0612-03-012	$2,002,589.00	7.8	Restore
FM1644	2009	0384 +00.5	0394 +01.5	2337-01-018	$3,048,922.00	11.0	Restore
SH0006	2009	0610 +00.0	0616 +01.0	0050-03-085	$2,117,247.00	7.0	Rehab

To account for the fact that the timing of construction projects is affected by many policy and funding factors, the percent sections with NN needs estimate for the 10 projects listed above was computed using pavement condition data from one year, three years, and five years prior to the actual construction year (see Figure 3.1). In six of the 10 projects, the percent of NN sections increases when moving from 1-year prior to 3-years prior. For all 10 projects, the percent of NN sections 5-years prior to construction was greater than 3-years prior to construction. In fact, 5-years prior to construction have the largest percent of NN sections for nine of the 10 projects, with the only exception occurring on FM 39, let in FY 2008. For SH 7, let in FY 2008, the 1-year and 5-year NN sections are equal. This increasing trend in %NN indicates that, in Bryan district, it takes one or two years to let a project after the pavement is identified as in need of maintenance or rehabilitation (based on condition). For the 1-year prior period, the percent of NN sections within Bryan district projects ranged between zero (perfect agreement between PMIS output and the actual project) to 77.8% (poor agreement between PMIS output and the actual project). On average, the percent of NN sections within Bryan district for all projects, across all years, 1-year prior to construction was 45 percent. For projects analyzed further (Figure 3.1) the average percent of NN sections for 1, 3, and 5 years prior to actual project construction year was 33 percent, 31 percent, and 42 percent, respectively.



	FM 60 '07	FM 485 '07	US 84 '07	FM 2562 '08	FM 39 '08	SH 7 '08	US 190 '08	FM 80 '09	SH 6 '09	FM 1644 '09
1-yr Prior	20.00%	0.00%	6.00%	12.50%	77.78%	66.67%	63.64%	0.00%	50.00%	4.76%
3-yr Prior	23.33%	8.33%	28.89%	8.33%	51.85%	55.56%	60.61%	6.25%	52.78%	18.46%
5-yr Prior	44.00%	27.78%	53.33%	25.00%	60.00%	66.67%	76.36%	8.86%	64.17%	20.18%

Figure 3.1. Percent NN Sections with Sample Construction Projects in Bryan District

3.2.2 Project Agreement Analysis for Beaumont District

Tables 3.7, 3.8, and 3.9 provide the same information for the Beaumont district as those above provided for the Bryan district.

Table 3.7. 2007 Construction Project Description and Needs Estimate Suggestions (Beaumont)

Project Type	# of Projects		NN	PM	LRhb	MRhb	HRhb	Total
Seal Coat	27	Length (mi)	100.5	34.3	4.4	6.9	0.5	146.5
		# of Sections	205	70	9	14	1	299
Overlay	8	Length (mi)	11.6	3.7	1.0	11.6	6.8	34.7
		# of Sections	34	11	3	34	20	102
Rehab	3	Length (mi)	13.2	2.0	0.0	2.9	0.0	18.1
		# of Sections	27	4	0	6	0	37.0
Restore	1	Length (mi)	3.8	0.9	0.0	0.0	0.0	4.7
		# of Sections	8	2	0	0	0	10
Repair	0	Length (mi)						
		# of Sections						
Mill & Overaly	7	Length (mi)	9.2	2.6	1.0	3.3	5.6	21.8
		# of Sections	28	8	3	10	17	66.0
Base Repair & Overlay	0	Length (mi)						
		# of Sections						
Resurface	19	Length (mi)	68.5	25.0	2.0	1.0	0.0	96.5
		# of Sections	137	50	4	2	0	193
Totals	**65**	**Length (mi)**	**206.7**	**68.6**	**8.4**	**25.7**	**12.9**	**322.3**
		% of Length	**64%**	**21%**	**3%**	**8%**	**4%**	
		# of Sections	**439**	**145**	**19**	**66**	**38**	**707**
		% of Sections	**62%**	**21%**	**3%**	**9%**	**5%**	

NN = Needs Nothing
PM = Preventative Maintenance
LRhb = Light Rehabilitation
MRhb = Medium Rehabilitation
HRhb = Heavy Rehabilitation

Table 3.8. 2008 Construction Project Description and Needs Estimate Suggestions (Beaumont)

Project Type	# of Projects		NN	PM	LRhb	MRhb	HRhb	Total
Seal Coat	26	Length (mi)	88.8	57.5	3.7	3.7	1.4	155.0
		# of Sections	193	125	8	8	3	337
Overlay	18	Length (mi)	86.5	35.7	1.9	2.8	0.0	126.9
		# of Sections	184	76	4	6	0	270
Rehab	2	Length (mi)	2.5	2.0	2.0	1.0	0.0	7.5
		# of Sections	5	4	4	2	0	15
Restore	2	Length (mi)	11.0	0.5	0.0	0.0	0.0	11.5
		# of Sections	22	1	0	0	0	23
Repair	4	Length (mi)	27.9	0.2	0.0	0.0	0.0	28.1
		# of Sections	133	1	0	0	0	134.0
Mill & Overaly	2	Length (mi)	0.4	11.4	0.4	0.4	0.0	12.8
		# of Sections	1	26	1	1	0	29.0
Base Repair & Overlay	0	Length (mi)						
		# of Sections						
Resurface	0	Length (mi)						
		# of Sections						
Totals	**54**	**Length (mi)**	**217.1**	**107.4**	**8.0**	**7.9**	**1.4**	**341.8**
		% of Length	**64%**	**31%**	**2%**	**2%**	**0%**	
		# of Sections	**538**	**233**	**17**	**17**	**3**	**808**
		% of Sections	**67%**	**29%**	**2%**	**2%**	**0%**	

NN = Needs Nothing
PM = Preventative Maintenance
LRhb = Light Rehabilitation
MRhb = Medium Rehabilitation
HRhb = Heavy Rehabilitation

Table 3.9. 2009 Construction Project Description and Needs Estimate Suggestions (Beaumont)

Project Type	# of Projects		NN	PM	LRhb	MRhb	HRhb	Total
Seal Coat	37	Length (mi)	122.0	70.0	3.5	5.5	0.0	201.0
		# of Sections	244	140	7	11	0	402
Overlay	9	Length (mi)	30.1	8.4	0.9	1.9	1.9	43.1
		# of Sections	97	27	3	6	6	139
Rehab	1	Length (mi)	0.0	0.9	0.0	0.5	0.5	1.8
		# of Sections	0	2	0	1	1	4
Restore	2	Length (mi)	0.5	1.5	1.0	1.0	0.5	4.5
		# of Sections	1	3	2	2	1	9
Repair	0	Length (mi)						
		# of Sections						
Mill & Overaly	2	Length (mi)	0.5	5.8	0.5	0.5	0.0	7.2
		# of Sections	1	12	1	1	0	15.0
Base Repair & Overlay	1	Length (mi)	0.8	0.4	0	0.8	0	2
		# of Sections	4	2	0	4	0	10
Resurface	0	Length (mi)						
		# of Sections						
Totals	**52**	**Length (mi)**	**153.9**	**86.9**	**5.9**	**10.1**	**2.8**	**259.6**
		% of Length	**59%**	**33%**	**2%**	**4%**	**1%**	
		# of Sections	**347**	**186**	**13**	**25**	**8**	**579**
		% of Sections	**60%**	**32%**	**2%**	**4%**	**1%**	

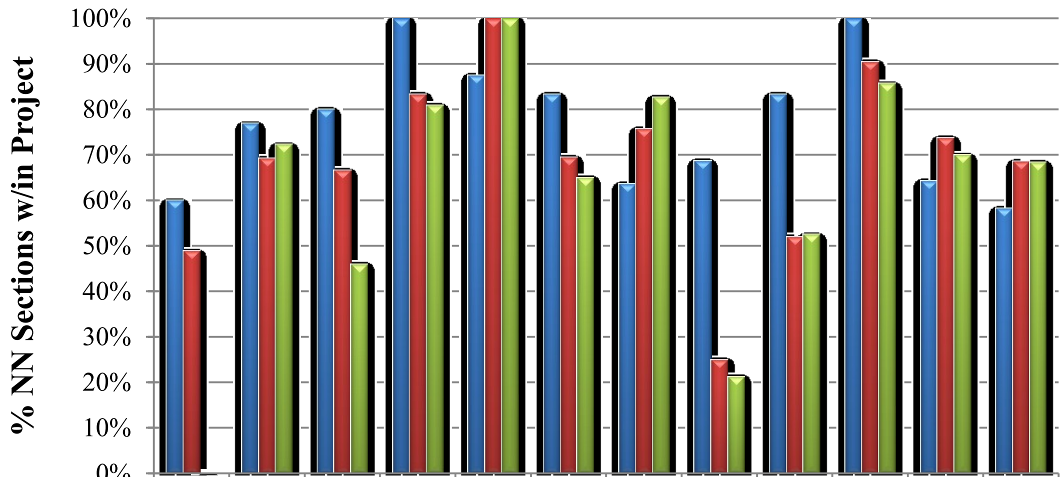
NN = Needs Nothing
PM = Preventative Maintenance
LRhb = Light Rehabilitation
MRhb = Medium Rehabilitation
HRhb = Heavy Rehabilitation

Table 3.9 indicates that of the 347 NN sections receiving work, 244 received a seal coat, over 70%. This information was for 2009 construction, however the impact of seal coat is significantly less for 2008 construction where 193 of the 538 NN sections receiving work were treated with a seal coat, in fact 184 NN sections received an overlay. From Table 3.8, it is not enough to only look at seal coat, the projects under resurfacing must also be evaluated for the number of NN sections. Resurfacing projects could also be classified as microsurface projects where the preservation technique used is the application of microsurface to the existing roadway. Of the three years analyzed, microsurfacing was only performed during this year and based on district interviews can be analyzed the same way at the proactive nature of seal coat projects. With this in mind, 342 of the 439 NN sections from 2007 construction were either a seal coat or resurfacing project. The point here is to continue to illustrate the inherent proactive nature of seal coat projects and that these types of projects contribute significantly to the lack of project agreement between the current needs estimate tool and actual construction activities. As with the Bryan data, these projects are eliminated from further evaluation for project agreement. Projects used in further analysis from the Beaumont district are detailed in Table 3.10.

Table 3.10. Beaumont District Construction Projects in FY 2007-2009

HWY	Cosnt. FY	BRM	ERM	Construction Cost	Length (mi)	Work Description
FM 421	2007	0740 +01.0	0748 +00.5	$1,471,613	7.5	Overlay
SH 105	2007	0722 +00.5	0734 +01.5	$10,941,440	13.0	Rehabilitation
FM 1136	2007	0434 +00.5	0438 +01.4	$1,171,634	4.7	Restoration
FM 770	2007	0454 +01.0	0456 +01.0	$1,141,373	2.0	Mill&Overlay
US 69	2007	0488 +00.0	0490 +01.0	$1,318,030	3.0	Mill&Overlay
FM 787	2008	0722 +00.0	0726 +01.8	$1,371,985	5.8	Overlay
US 190	2008	0874 +01.0	0880 +00.4	$1,280,850	5.4	Overlay
FM 562	2008	0466 +00.0	0474 +00.0	$813,390	8.0	Overlay
SH 63	2008	0776 +00.2	0788 +00.0	$1,800,918	12.3	Overlay
FM 1293	2008	0728 +00.0	0734 +01.0	$1,126,384	7.0	Restoration
FM 770	2009	0442 +00.0	0448 +00.0	$1,210,664	4.2	Overlay
FM 770	2009	0448 +00.1	0450 +00.0	$531,627	2.0	Overlay
SH 61	2009	0460 +00.1	0466 +00.0	$814,457	6.0	Overlay

From Table 3.10, it is clear that the FM 770 overlay projects let for construction in FY 2009 are adjacent and therefore for further analysis these two projects will be combined into one. The needs estimate for these projects will be generated for 1-year prior, the combination of 3-years prior, and the combination of 5-years prior to construction in an effort to see if the number of NN sections decreases using a historical perspective. This information is displayed in Figure 3.2.



	FM 421 '07	SH 105 '07	FM 1136 '07	FM 770 '07	US 69 '07	FM 787 '08	US 190 '08	FM 562 '08	SH 63 '08	FM 1293 '08	FM 770 '09	SH 61 '09
1-yr Prior	60.00	76.92	80.00	100.0	87.50	83.33	63.64	68.75	83.33	100.0	64.29	58.33
3-yr Prior	48.89	69.23	66.67	83.33	100.0	69.44	75.76	25.00	52.05	90.48	73.81	68.57
5-yr Prior	0	72.31	46.00	80.95	100.0	65.00	82.69	21.25	52.50	85.71	70.00	68.42

Figure 3.2. Percent NN Sections with Sample Construction Projects in Beaumont District

Eight of the 12 projects from the Beaumont district had the percent of NN sections decrease when moving from 1-year prior to construction to the combination of 3-years prior to construction, thus helping project agreement. Unlike Bryan, many of the projects had fewer NN sections with the combination 5-years prior to construction rather than the 3-year combination. The main conclusion that can be drawn from this is that looking only 1-year prior to construction is not the best evaluation, historical performance should be evaluated, but even using historical agreement, the Needs Estimate does not completely agree with district preservation decisions. For the Beaumont district, the percent of NN sections receiving work for all projects from FY 2007 to FY 2009 was 63 percent. For projects undergoing further analysis with heavier preservation action than a seal coat, the average percent of NN sections 1, 3, and 5 years prior to construction was 76 percent, 68 percent, and 63 percent, respectively.

3.2.3 Project Agreement Analysis for Dallas District

Tables 3.11, 3.12, and 3.13 present the agreement and construction data evaluated for the Dallas district.

Table 3.11. 2007 Construction Project Description and Needs Estimate Suggestions (Dallas)

Project Type	# of Projects		NN	PM	LRhb	MRhb	HRhb	A900	Total
Seal Coat	26	Length (mi)	45.3	28.6	12.3	12.3	0.9	48.4	147.8
		# of Sections	103	65	28	28	2	110	336
Base Repair & Seal	3	Length (mi)	7.4	12.3	2.9	4.9	0.5	20.6	48.5
		# of Sections	15	25	6	10	1	42	99
Base Repair & Level-up	6	Length (mi)	3.0	2.5	1.5	4.0	2.5	7.0	20.5
		# of Sections	6	5	3	8	5	14	41
Full Depth Conc Repair	5	Length (mi)	8.7	0.6	2.3	4.2	6.5	0.0	22.23
		# of Sections	46	3	12	22	34	0	117
Base Repair	2	Length (mi)	8.0	0.9	0.0	2.4	0.5	0.0	11.8
		# of Sections	17	2	0	5	1	0	25
Rehab	4	Length (mi)	1.1	6.6	0.7	4.8	0.2	0.0	13.4
		# of Sections	5	30	3	22	1	0	61
Base Repair & Overlay	1	Length (mi)	7	0.5	0	0	0	0	7.5
		# of Sections	14	1	0	0	0	0	15
Microsurface	3	Length (mi)	0.0	3.3	0.0	1.9	0.9	8.0	14.1
		# of Sections	0	7	0	4	2	17	30
Pvt. Repair & Overlay	3	Length (mi)	4.0	7.9	2.2	4.4	3.1	7.7	29.3
		# of Sections	18	36	10	20	14	35	133
Reconstruct	0	Length (mi)							
		# of Sections							
Mill & Inlay/Overlay	0	Length (mi)							
		# of Sections							
Add Width	0	Length (mi)							
		# of Sections							
Totals	**53**	**Length (mi)**	**84.5**	**63.2**	**21.9**	**38.9**	**15.0**	**91.7**	**315.1**
		% of Length	**27%**	**20%**	**7%**	**12%**	**5%**	**29%**	
		# of Sections	**224**	**174**	**62**	**119**	**60**	**218**	**857**
		% of Sections	**26%**	**20%**	**7%**	**14%**	**7%**	**25%**	

NN = Needs Nothing
PM = Preventative Maintenance
LRhb = Light Rehabilitation
MRhb = Medium Rehabilitation
HRhb = Heavy Rehabilitation

Table 3.12. 2008 Construction Project Description and Needs Estimate Suggestions (Dallas)

Project Type	# of Projects		NN	PM	LRhb	MRhb	HRhb	A900	Total
Seal Coat	47	Length (mi)	55.8	83.7	37.4	36.9	6.3	87.8	307.8
		# of Sections	124	186	83	82	14	195	684
Base Repair & Seal	0	Length (mi)							
		# of Sections							
Base Repair & Level-up	1	Length (mi)	0.0	0.0	0.0	1.5	0.0	0.5	2.0
		# of Sections	0	0	0	3	0	1	4
Full Depth Conc Repair	3	Length (mi)	3.8	0.5	0.3	1.4	0.0	0.3	6.2
		# of Sections	14	2	1	5	0	1	23
Base Repair	0	Length (mi)							
		# of Sections							
Rehab	0	Length (mi)							
		# of Sections							
Base Repair & Overlay	1	Length (mi)	1	3.5	0	0	0	4.5	9
		# of Sections	2	7	0	0	0	9	18
Microsurface	0	Length (mi)							
		# of Sections							
Pvt. Repair & Overlay	2	Length (mi)	1.5	8.3	2.9	0.5	0.5	0.0	13.7
		# of Sections	3	17	6	1	1	0	28
Reconstruct	1	Length (mi)	0.0	1.5	0.0	1.5	0.5	0.0	3.5
		# of Sections	0	3	0	3	1	0	7
Mill & Inlay/Overlay	2	Length (mi)	2.1	0.3	0.8	1.3	0.5	1.8	6.8
		# of Sections	8	1	3	5	2	7	26
Add Width	0	Length (mi)							
		# of Sections							
Totals	**57**	**Length (mi)**	**64.1**	**97.8**	**41.3**	**43.0**	**7.8**	**94.8**	**349.0**
		% of Length	**18%**	**28%**	**12%**	**12%**	**2%**	**27%**	
		# of Sections	**151**	**216**	**93**	**99**	**18**	**213**	**790**
		% of Sections	**19%**	**27%**	**12%**	**13%**	**2%**	**27%**	

NN = Needs Nothing
PM = Preventative Maintenance
LRhb = Light Rehabilitation
MRhb = Medium Rehabilitation
HRhb = Heavy Rehabilitation

Table 3.13. 2009 Construction Project Description and Needs Estimate Suggestions (Dallas)

Project Type	# of Projects		NN	PM	LRhb	MRhb	HRhb	A900	Total
Seal Coat	40	Length (mi)	97.7	101.3	24.3	41.0	12.2	36.0	312.3
		# of Sections	217	225	54	91	27	80	694
Base Repair & Seal	0	Length (mi)							
		# of Sections							
Base Repair & Level-up	0	Length (mi)							
		# of Sections							
Full Depth Conc Repair	0	Length (mi)							
		# of Sections							
Base Repair	0	Length (mi)							
		# of Sections							
Rehab	1	Length (mi)	0.0	0.0	0.0	1.4	0.9	0.0	2.3
		# of Sections	0	0	0	3	2	0	5
Base Repair & Overlay	0	Length (mi)							
		# of Sections							
Microsurface	0	Length (mi)							
		# of Sections							
Pvt. Repair & Overlay	3	Length (mi)	0.8	3.7	5.3	8.6	0.4	0.0	18.9
		# of Sections	2	9	13	21	1	0	46
Reconstruct	0	Length (mi)							
		# of Sections							
Mill & Inlay/Overlay	3	Length (mi)	0.0	1.1	0.2	2.7	1.8	0.0	5.8
		# of Sections	0	6	1	15	10	0	32
Add Width	3	Length (mi)	0.0	7.7	3.8	2.4	1.0	6.2	21.1
		# of Sections	0	16	8	5	2	13	44
Totals	**50**	**Length (mi)**	**98.5**	**113.7**	**33.7**	**56.0**	**16.2**	**42.2**	**360.3**
		% of Length	**27%**	**32%**	**9%**	**16%**	**5%**	**12%**	
		# of Sections	**219**	**256**	**76**	**135**	**42**	**93**	**821**
		% of Sections	**27%**	**31%**	**9%**	**16%**	**5%**	**11%**	

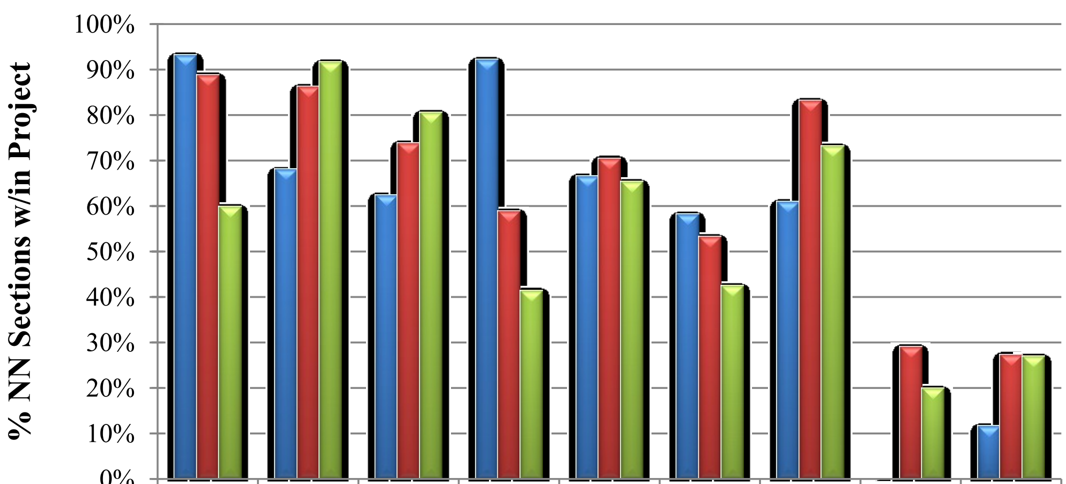
NN = Needs Nothing
PM = Preventative Maintenance
LRhb = Light Rehabilitation
MRhb = Medium Rehabilitation
HRhb = Heavy Rehabilitation

From Tables 3.11, 3.12, and 3.13, it appears the number of NN sections for Dallas district construction is far fewer than from other districts, however this percentage is deceptive. Within each of these tables, there is a column for the number of sections that have an M&R treatment triggered by reason code A900. This is important because while it returns a preventative maintenance suggestion in the needs estimate; it is equivalent to a NN suggestion. A900 returns a PM suggestion based on the date of last surface. From the history in PMIS, it is clear the last time the date of surfacing has been updated for the Dallas district is October 2004 and therefore A900 is a common return in the needs estimate, when in reality the reason code is A999, or NN. Combining both the NN sections and the A900 sections results in the Dallas information becoming more like Bryan and Beaumont with 52 percent, 46 percent, and 38 percent of sections requiring nothing according to the needs estimate in the years analyzed.

Table 3.14 provides a list of the projects from the Dallas district that will be evaluated further and Figure 3.3 offers a graphical interpretation of the number of NN sections within these project limits.

Table 3.14. Dallas District Construction Projects in FY 2007-2009

HWY	Cosnt. FY	BRM	ERM	Construction Cost	Length (mi)	Work Description
FM 156	2007	0248 +00.0	0256 +00.0	$1,590,784.00	7.4	Base Repair&Overlay
FM 1173	2007	0552 +00.0	0562 +01.0	$466,708.00	10.8	Base Repair&Seal Coat
FM 2281	2007	0246 +00.0	0246 +01.7	$240,925.00	1.7	Rehabilitation
FM 2933	2007	0230 +01.0	0236 +01.6	$783,293.00	6.5	Base Repair&Level-up
US 80	2007	0661 - 00.4	0662 +00.0	$509,398.00	1.4	Full Depth Concrete Repair
FM 1382	2008	0274 +00.3	0276 +01.0	$1,730,444.00	2.7	Mill, Level-up, Overlay
FM 428	2008	0568 +00.0	0576 +01.0	$1,786,704.00	9.0	Base Repair&Overlay
FM 639	2009	0586 +00.0	0590 +00.0	$3,066,087.00	6.4	Pavement Repair&Overlay
FM 1126	2009	0310 +00.5	0316 +03.1	$4,221,149.00	8.6	Pavement Repair&Overlay



	FM 156 '07	FM 1173 '07	FM 2281 '07	FM 2933 '07	US 80 '07	FM 1382 '08	FM 428 '08	FM 639 '09	FM 1126 '09
1-yr Prior	93.33%	68.18%	62.50%	92.31%	66.67%	58.33%	61.11%	0.00%	11.76%
3-yr Prior	88.89%	86.36%	73.91%	58.97%	70.59%	53.33%	83.33%	29.17%	27.45%
5-yr. Prior	60.00%	91.82%	80.65%	41.54%	65.52%	42.59%	73.33%	20.00%	27.06%

Figure 3.3. Percent NN Sections with Sample Construction Projects in Dallas District

From Figure 3.3, it is clear that the projects along FM 156, FM 2933, and FM 1382 have more agreement between the needs estimate and the actual construction by using a historical evaluation. For these three projects, the agreement is improved when moving from the 3-year combination to the 5-year combination. As a total, for the three years of construction projects analyzed, the average percent of NN sections (including A900 sections) for all projects was 45 percent in the year prior to construction. For the nine projects with a preservation treatment heavier than seal coat or microsurface that were analyzed further, the average percent of NN sections for 1, 3, and 5-years prior to construction was 59 percent, 66 percent, and 61 percent respectively.

From the analysis above, it is clear that the Needs Estimate recommendations and actual district decisions do not agree. To overcome this disagreement a tool was created to better match district decisions by including variables identified by district decision makers and weighting those variables based on input from a decision maker. Before discussing the new method, brief discussion is included that offers practical insight into the current disagreement between the Needs Estimate and actual preservation decisions.

3.3 POSSIBLE EXPLANATIONS FOR DISAGREEMENT BETWEEN THE NEEDS ESTIMATE AND ACTUAL DISTRICT DECISIONS BASED ON OBSERVATIONS DURING DATA ANALYSIS

A list is provided that offers possible explanations for some of the disagreement between the current Needs Estimate suggestions and actual district preservation decisions. These explanations were discovered during the analysis of data and capabilities currently available in PMIS.

- Proactive nature of seal coat and microsurfacing programs
- Inability to consider historical distress issues
- Use of in-house maintenance forces to preserve the pavement in an acceptable condition
- Use of routine maintenance contracts to repair sections (this information was not available for the same analysis as Category 1 funded projects)
- Inability of PMIS to move beyond the section level and aggregate information to suggest "district" type projects
- Data collection issues
- Reason code definitions causing "false positives"

A discussion of how the method created in this research effort overcomes many of these limitations is offered after a glaring issue dealing with data collection and reason code problems is addressed. At times, there were drastic movements in the percent of NN sections within a district's network. This is illustrated in Table 3.15.

Table 3.15. District Needs Estimate Summaries

Bryan District										
	Total					Asphalt Pavements				
FY	% NN	% PM	% LRhb	% MRhb	% HRhb	% NN	% PM	% LRhb	% MRhb	% HRhb
2004	66%	20%	8%	5%	1%	66%	20%	8%	5%	1%
2005	55%	27%	10%	6%	1%	55%	27%	10%	6%	1%
2006	58%	23%	11%	7%	1%	58%	23%	11%	6%	1%
2007	61%	22%	9%	6%	2%	61%	23%	9%	6%	1%
2008	42%	43%	9%	4%	2%	42%	43%	9%	4%	2%
2009	73%	12%	9%	5%	1%	73%	12%	9%	5%	1%
Beaumont District										
	Total					Asphalt Pavements				
FY	% NN	% PM	% LRhb	% MRhb	% HRhb	% NN	% PM	% LRhb	% MRhb	% HRhb
2004	57%	31%	3%	6%	3%	58%	36%	2%	3%	1%
2005	57%	27%	4%	9%	3%	59%	32%	3%	5%	1%
2006	64%	22%	3%	8%	3%	66%	26%	3%	4%	2%
2007	63%	26%	3%	5%	3%	65%	30%	1%	3%	1%
2008	63%	26%	3%	6%	2%	64%	29%	2%	3%	1%
2009	69%	20%	5%	6%	1%	69%	23%	4%	3%	1%
Dallas District										
	Total					Asphalt Pavements				
FY	% NN	% PM	% LRhb	% MRhb	% HRhb	% NN	% PM	% LRhb	% MRhb	% HRhb
2004	52%	19%	11%	15%	3%	53%	26%	8%	11%	2%
2005	58%	14%	10%	14%	4%	61%	19%	7%	10%	3%
2006	52%	13%	11%	19%	6%	54%	19%	9%	13%	5%
2007	45%	23%	10%	17%	5%	44%	31%	8%	13%	4%
2008	40%	21%	11%	21%	7%	40%	29%	10%	14%	6%
2009	54%	14%	10%	17%	6%	57%	18%	9%	11%	5%

Table 3.15 clearly shows drastic drops in the quantity of NN sections for the Bryan district in FY 2008 and for the Dallas district in FY 2007 and 2008. For Bryan, the change from FY 2007 to FY 2008 is almost 20 percent, while the subsequent increase from FY 2008 to FY 2009 is over 30 percent. Dallas experiences a similar decline in NN sections (this includes sections that have reason code A900) from FY 2006 to FY 2007 where the drop was over 10 percent and while it remains steady through FY 2008, there was a rise of almost 17 percent from FY 2008 to FY 2009.

Additional investigation proved that reason code A705 is the major culprit for the drastic swings in percent of NN sections. The information from Table 3.15 and the aforementioned drastic movements are graphically illustrated in Figures 3.4 and the specific reason code behind the movement is graphically depicted in Figure 3.5.

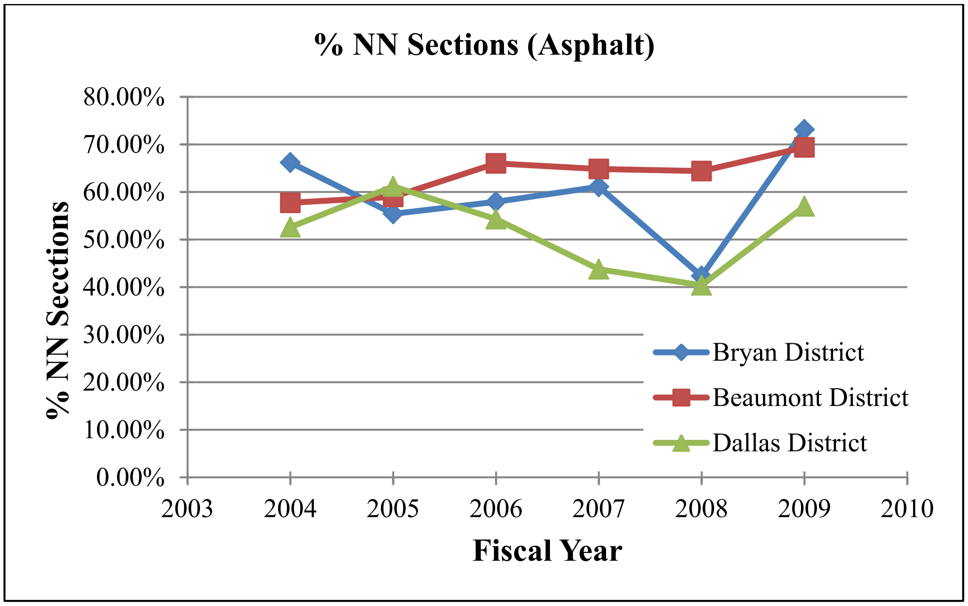


Figure 3.4. Percent of Sections with NN Reason Codes for only Asphalt Pavement Types

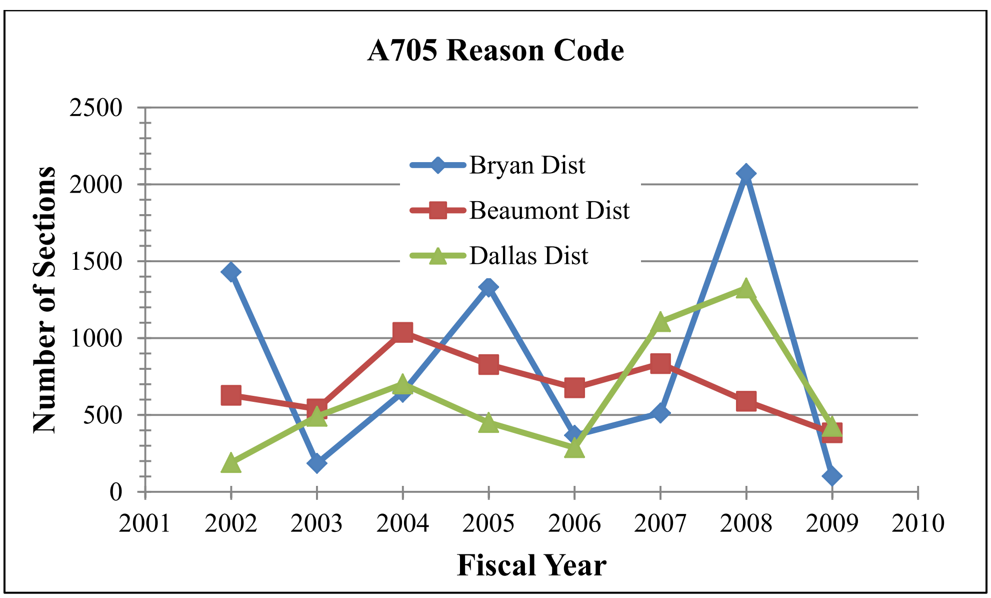


Figure 3.5. Sections with A705 Reason Code

The description behind A705 is “Deep Rutting greater than 0 percent,” returning a preservation treatment suggestion of PM. Zero percent seems to be a strenuous limit that puts significant onus on the equipment used to measure deep rutting and any small defect that records a fraction of rutting will result in a PM M&R suggestion for a particular section.

The method created seeks to overcome many of the limitations within the current Needs Estimate. This research does not seek to create a method that overcomes the proactive decisions behind the seal coat programs, but other than that the rest of the items on the list are addressed. Historical distress information is built into the new method that is also thought to account for some routine maintenance activities, but routine maintenance is further accounted for by including money spent on maintenance as a decision variable. The Bryan district is consulted regarding the use of routine maintenance contracts to determine if the new method has even better agreement when considering these contracts. An effort is made in the new method to “drive” down the road and aggregate information to create realistic project suggestions, not just merely information within a ½-mile section. Data collection will always remain an area that can be improved; however by using historical information, it is believed that a realistic view of the pavement will come forth during the analysis. The use of data and possible false positives is further insulated by basing the new method on actual field information which allows the bounds of the new method to be set on actual network conditions, not only theoretical projections. All of this is discussed further in the next section.

4. NEW PROJECT SELECTION AND PRIORITIZATION METHOD FOR NETWORK-LEVEL PAVEMENT MANAGEMENT

4.1 AHP FOR PROJECT SELECTION

To bridge the gap between PMIS and the project selection process at TxDOT, the parameters associated with making pavement preservation decisions must be identified first; and then a method must be developed that can use data available in PMIS to determine and unite these decision parameters to help select candidate projects. Questions such as the following must be answered: is a section with 5000 vehicles per day, one failure, 10% Alligator Cracking, and an IRI of 127 inch per mile in more need of preservation work than a section with 10,000 vehicles per day, 125 feet of Longitudinal Cracking, and an IRI of 148 inch per mile? This must be done for every section within the roadway network. The researcher has developed a method to answer this type of question using the Analytic Hierarchy Process (AHP).

The AHP requires formulating the problem of selecting pavement preservation projects in a hierarchal fashion. This hierarchal thought is believed to match how individuals make actual decisions. In regards to a decision, there is an ultimate goal in mind with different components contributing to that ultimate goal. For example, when dressing in the morning, the ultimate goal is to get dressed, but one level below that could be the components of one's attire such as socks, shoes, pants, and shirts. Below this level is a third level with different types of socks, shoes, pants, and shirts. To achieve the ultimate goal of getting dressed, one must break down the decision into its components, compare the options of each of the components and synthesize these comparisons to reach the goal. The AHP formalizes this thought process and is utilized in this research for selecting pavement preservation projects. The hierarchy of the project selection decision will be stratified in three levels, as follows:

1. Project Selection Number: At this level, pavement managers can evaluate each section within the pavement network to determine how important one section of pavement is compared to another section of pavement, considering the relative weights of each decision parameter.
2. Decision Parameter Level: At this level, pavement managers can set the relative weights of the various parameters considered in the decision making process. The AHP is applied to the parameters to determine the weights and this level also allows pavement managers to determine how sections rank when considering each individual parameter.
3. Section vs. Section Level: At this level, each section competes against every other section to determine how important it is against every other section for every decision parameter.

This hierarchy is illustrated in Figure 4.1.

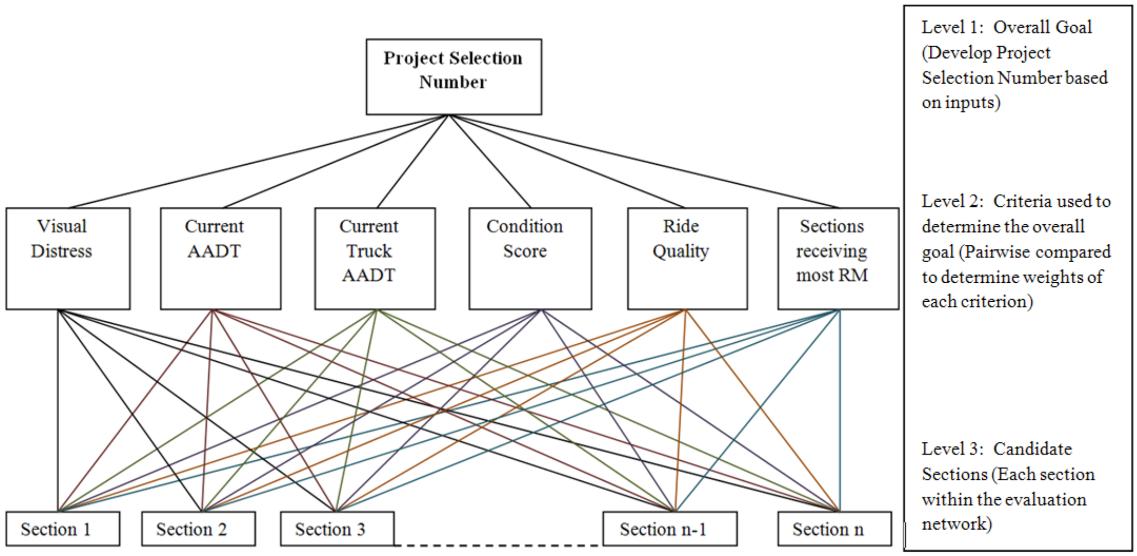


Figure 4.1. Three Level Project Selection Number Hierarchy

To completely bridge the gap between network-level and project-level decision making, these newly established project selection numbers must be aggregated to move from the section level to the project level. This is completed and discussed later in the thesis, but first a discussion on the determination of decision criteria located at level two of the hierarchy is provided.

4.2 DETERMINATION OF DECISION CRITERIA

The decision parameters used in the creation of the selection number were determined through a multistep process. The first step included providing decision makers in the Beaumont, Bryan, Dallas, and Tyler districts with a survey created by the researcher to help define the decision making variables and develop a preliminary sense of perceived importance. The table presented to decision makers included a list of 25 possible variables considered when making pavement preservation decisions. The decision makers were asked to assign a generic importance level to each parameter of, no importance, very low, low, medium, high, or very high. This importance gauge was applied to each parameter when considering the following questions:

1. Does this section of roadway require work? and if so,
2. What type of preservation action is required?

The goal was to take the weights assigned to each of these questions and narrow the list of decision making parameters to a manageable list that could be used in the AHP. A blank copy of the entire survey is provided in Appendix C along with a summarized survey that displays the number of responses associated with each possible parameter.

To narrow the list, a simple weighted average was used to determine which parameters were more important than others. For computational purposes, the descriptive importance levels (obtained from the survey) were converted to numerical levels as follows:

- Not important = zero
- Very Low Importance = 1
- Low Importance = 2
- Medium Importance = 3
- High Importance = 4
- Very High Importance = 5

The numerical importance levels were summed across and divided by the total number of responses to determine the weighted average for each of the decision parameters. Table 4.1 lists the top ten parameters to the question, “does a particular section require M&R work?" Table 4.2 lists the top ten parameters answering the question, what type of M&R action should be applied to a section requiring work?

Table 4.1. Top Ten Decision Parameters (Does this Section Need Preservation?)

Rank	Input Parameters	Weighted Avg.	Highest Ranking	Lowest Ranking	Most Frequent Ranking
1	Visual Distress (Site Visit)	4.23	Very High	Low	Very High
2	Current ADT	4.15	Very High	Medium	High
3	Current Truck ADT	3.85	Very High	Low	High
4	PMIS Distress Score	3.77	Very High	Low	High
5	Sections that receive the most RM[1]	3.54	Very High	None	Very High/High
6	Projected 18-kip Equivalent	3.50	Very High	Low	High
T7	Future Truck ADT	3.46	Very High	Low	High
T7	PMIS Condition Score	3.46	Very High	Low	High
9	Rutting	3.38	Very High	Low	High/Medium
T10	Future ADT	3.31	Very High	Low	High/Low
T10	PMIS Individual Distresses	3.31	Very High	None	Medium

RM[1] = Routine Maintenance (maintenance done with TxDOT forces)

Table 4.2. Top Ten Decision Parameters (What Type of Preservation Action Should be Performed?)

Rank	Input Parameters	Weighted Avg.	Highest Ranking	Lowest Ranking	Most Frequent Ranking
1	Visual Distress (Site Visit)	4.38	Very High	Low	Very High
2	Current Truck ADT	4.31	Very High	Medium	Very High
T3	Current ADT	4.23	Very High	Medium	High
T3	Additional Field Testing	4.23	Very High	Low	Very High
5	Future Truck ADT	4.00	Very High	Medium	High
6	Projected 18-kip Equivalent	3.92	Very High	Low	High
7	Future ADT	3.69	Very High	Low	Medium
8	Rutting	3.54	Very High	Low	High
9	PMIS Distress Score	3.31	Very High	Low	High
10	PMIS Individual Distresses	3.15	Very High	None	High

From Table 4.1 and Table 4.2, it is obvious that many of the same parameters deemed important in determining whether or not a pavement section receives preservation work are also important when determining what type of work is needed. It is also obvious that a site visit to determine the actual distresses present is the most important parameter in both questions. Current levels of ADT, both complete ADT and truck ADT are also at the top of the list. There are certain variables used in answering the question, what preservation action should be performed, that cannot be quantified outside of the actual pavement design process. Specifically, additional field testing is high on the list of parameters included in Table 4.2, but it falls outside of the top ten when considering if a section needs work. Therefore this variable is not included in further development of the method; however it should be mentioned that if TxDOT or another managing agency wished to include this parameter it could be incorporated into the method easily. Obviously to work this parameter into consideration, the data must be available and that would include collecting relatively detailed data at the network-level, such as falling weight deflectometer (FWD) data and ground penetrating radar (GPR). Based on the results presented in Table 4.1 and Table 4.2 collection of this data can be limited to project specific needs, however to completely bridge the gap between network and project level decision making, this information may need to be collected and included in the pavement management system.

Other parameters can be eliminated from further consideration because they are essentially duplicates of another variable. For example, site visit and distress score are included in the top ten in both tables. While these two are not exactly the same, the information that is included in both variables is the same. Regardless of the accuracy of the data, the ability to completely replace an actual site visit cannot currently be achieved; therefore recorded distress information within PMIS is used in an effort to describe the pavement in the same manner that a site visit would describe the section. Similarly, distress score and visual distress are interchangeable and there is no need to continue to consider both parameters in the AHP. The same interchangeability applies to future truck ADT and projected 18-kip equivalent single axle load (ESAL). Because truck ADT is normally more accurate (and easier to obtain) than the 18-kip ESAL data, the researcher has decided to use future truck ADT rather than 18-kip ESAL.

Based on the results of the districts questionnaire and the subsequent refinements, the final eight most important parameters were selected for use in the creation of the project selection number:

1. Visual Distress
2. Current ADT
3. Current Truck ADT
4. Future ADT
5. Future Truck ADT
6. Condition Score
7. Ride Quality
8. Section that receive the most routine (in-house) maintenance

As described in Section 3, the researcher has determined that three years' worth of distress data should be evaluated to more accurately describe the true condition of a pavement section. Using three years' data allows for capturing the effect of routine maintenance on pavement's condition. It is not uncommon for a section of pavement to exhibit fluctuations in Condition Score, Distress Score, or Needs Estimate due to actions performed by TxDOT maintenance forces. Through experience and conversations with district personnel, it is known that these M&R actions are often reactive in nature and serve merely as a "Band-Aid," while not actually solving the deterioration problem. However, these "Band-Aids" will often create an improved Condition or Distress Score for the section, while not accurately reflecting the actual preservation needs of the section. To account for fluctuations in distress data, the AHP was applied to the individual distress present over a three year period to develop a distress number that can be used as a representative of the visual distress parameter when calculating a project selection number. The creation of this visual distress parameter requires additional application of the AHP to the various distresses within the network. The determination of this distress number is discussed in detail later in the report.

A possible decision making component that surprisingly did not finish in the top ten for either table was ride quality, even though one of the decision makers from the Tyler district made the statement that the public expects a smooth ride. In fact, when answering the question does a section of roadway require a preservation action, ride quality finished tied for 17th with a weighted average of 2.62. When determining what type of preservation action should be applied, ride quality tied for 15th with a weighted average of 2.69. Ride quality never received a "Very High" ranking in either of the questionnaires. There are several possible explanations for this apparent low consideration for ride quality. Based on interviews with Bryan district personnel, it is known that due to the expansive nature of the soils in the area, poor ride quality is somewhat expected and therefore receives much less consideration than other parameters. Dallas district personnel indicated that the belief in the district is that many of the poor ride sections within the district are located on jointed concrete pavement frontage roads. Many of these roads are high volume roadways with a high density of driveways where traffic is forced to travel well below the posted speed. It is believed that these roadways do not have a significant amount of distress and that ride quality is not a significant issue because of the low speeds and the large number of access points. Also, construction on a roadway with this type of traffic volume proves problematic not only for motorists but for businesses along the access road. This belief has led to the mindset that ride quality is of secondary importance to other components in the decision making process. Beaumont district has a belief that most of the ride problems within the district are on older sections of jointed concrete pavement. The district staff indicated that while these sections are fairly old, the actual structural distresses present are minimal and therefore preservation dollars are better spent elsewhere. The Tyler district indicated that ride quality is an important parameter and should be considered when making pavement preservation decisions, but while making this statement, the decision makers indicated that it is believed most of the ride quality issues within the district are due to the manifestation and propagation of other distresses such as Alligator Cracking and Failures. This is not surprising in an urban district consisting of predominately flexible pavements.

Considering the above explanations, the low rating of ride quality as a decision making parameter is not surprising, however the researcher has chosen to include it as a variable to be considered further. This inclusion is based on several reasons, the first of which is the creation of the ride quality specification in TxDOT's standard specifications. Item 585, Ride Quality, spells out the expectation of the contractor with regards to smoothness of ride. Associated with these specifications are pay adjustments based on ride quality (Texas Department of Transportation (TxDOT) 2004). The expectation for a smooth ride from a contractor along with the attachment of beneficial and punitive possibilities through the specification warrant the further consideration of ride quality when making pavement preservation related decisions. Furthermore, ride quality, specifically the International Roughness Index (IRI), has been used to help agencies calculate user costs and vehicle operating costs. One study in particular is of the San Francisco Bay Area roadway network that uses equations where vehicle operating costs (VOC) are a function of IRI. The San Francisco Bay Area study references World Bank work establishing the connection between VOC and pavement roughness (Dewan and Smith 2002). A more general study discusses the cost a vehicle will incur as it drives over rougher roadways. This general study focuses not only on passenger cars, but also on fleet vehicles with the intent to determine the associated increase in cost with increase in IRI (Barnes and Langworthy 2004). All of these facts helped the researcher decide that despite ride quality's low ranking in the initial survey, it should be included as the method moves forward.

Finally, since the Bryan district does not record traffic growth factors in PMIS, and the area of study is within the district, Future ADT and Future Truck ADT will no longer be considered in this application. However, these two parameters should be included when this data becomes available in PMIS. To fully make the move to proactive decision making, future traffic should be included in the process and the initial survey results indicated that decision makers see this information as an important consideration when making pavement preservation decisions. The elimination of these parameters results in the six decision parameters located on level two of the hierarchy displayed in Figure 4.1. To move forward, the importance of each decision parameter must be established in the way the Bryan district weights the parameters when making preservation decisions.

4.3 RELATIVE IMPORTANCE ACROSS DECISION PARAMETERS

4.3.1 Introduction to the AHP

The AHP is constructed on a unique importance rating scale specifically designed to deal with multi-criteria decision making. The creation of this rating scale is based on the belief that for a scale to be used it must consist of objects, numbers, and a mapping scheme to assign the objects to the numbers. This importance rating scale ranges from 1 to 9. The odd numbers (1, 3, 5, 7, and 9) represent the primary importance intensity values, while the even numbers, 2, 4, 6, and 8 represent intermediate importance intensity values. This is illustrated in Table 4.3.

The scale is then used to compare the input parameters in a pairwise fashion to determine how much more or less important one parameter is to the other. The parameters are not compared to the decision as a whole; rather they are compared with each other to decide how they compete for importance in the decision as a whole. The pairwise comparison builds an *nxn* matrix consisting of the number of parameters included in the decision. The weights associated with the parameters are developed by calculating the principal eigenvector associated with the maximum eigenvalue for the pairwise matrix. This principal eigenvector is normalized to create a relative ratio scale that can be used as the priority vector or more simply put, weights associated with each parameter. The calculation of an eigenvalue and eigenvector is fairly straightforward and presented prior to Table 4.3.

Eigenvector calculations:

$$
\begin{aligned}
&if\ \ A = nxn\ matrix \\
&and\ I = identity\ matrix \\
&then\ the\ maximum\ eigenvalue, \lambda_{max}, is\ computed\ by \ldots \\
&\det(A - \lambda_{max} I) = 0, \\
&where\ \det\ is\ the\ determinant \\
&the\ eigenvector\ associated\ with\ \lambda_{max}\ is\ found\ by \ldots \\
&Ax = \lambda_{max} x \\
&where\ x = eigenvector\ associated\ with\ \lambda_{max}
\end{aligned}
$$

Table 4.3. AHP Weighting Scheme

Weight of Importance	Definition (from Saaty 1990a)	Explanation (from Saaty 1990a)
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

As the matrix increases in size, these calculations can become cumbersome; fortunately there are computational tools available to help overcome the exploding size of the problem. Python 2.6 is used to perform the necessary mathematical operations to the matrix to find the eigenvalue and eigenvectors for this research.

A consistency ratio (CR) is used to assess the consistency of the decision maker in assigning the importance intensity values in the AHP. The CR is computed as follows:

$$CR = \frac{CI}{RI}$$

$$CI = \frac{(\lambda_{max} - n)}{(n-1)}$$

$$where: n = size\ of\ matrix\ and\ \lambda_{max} = maximum\ eigenvalue$$

The RI value in the above equation is termed the random consistency index and is predefined within the AHP method based on the size of the matrix. The AHP method suggests that CR should be less than 10% (Saaty 1990b). This threshold CR value essentially implies that the method will allow for up to 10% error in human judgment during the pairwise comparison phase. Checking the CR is a way for the method to guard against inconsistent measurements that humans often make. For example, the CR is in place to make sure a decision maker does not rate ADT as more important than ride quality, ride quality more important than distress score, but distress score more important than ADT. More precisely, the CR is in place to help test the consistency of ratings applied to the comparisons. For example, rather than testing transitivity, the CR helps overcome a decision maker rating ADT three times as important as ride quality, ride quality twice as important as distress score, but ADT only twice as important as distress score.

4.3.2 Determination of Relative Importance

Based on the information and description of Figure 4.1 and the knowledge that the AHP operates on a matrix level for pairwise comparisons, the parameters at level two of the hierarchy must be inserted into a 6x6 matrix. This matrix is illustrated in Figure 4.2.

	Visual Distress	Current ADT	Current Truck ADT	Condition Score	Ride Quality	Sections that receive most Maintenance
Visual Distress	1					
Current ADT		1				
Current Truck ADT			1			
Condition Score				1		
Ride Quality					1	
Sections that receive most Maintenance						1

Figure 4.2. 6x6 Project Selection Parameter Matrix

The researcher interviewed one decision maker at the Bryan district to aid in determining appropriate importance intensity values for the matrix shown in Figure 4.2. For purposes of simplifying the interview of the Bryan district decision maker, only the primary weights are used, as shown in Table 4.4.

Table 4.4. Definition of AHP Weights Provided to TxDOT

Weight	Definition
1	Each variable is equally as important as the other
3	One variable is minimally more important than the other
5	One variable is moderately more important than the other
7	One variable is significantly more important than the other
9	One variable is drastically more important than the other

The Bryan district decision maker used in the study completed the matrix as shown in Figure 4.3.

	Visual Distress	Current ADT	Current Truck ADT	Condition Score	Ride Quality	Sections that receive most Maintenance
Visual Distress	1	7	5	1	7	7
Current ADT	1/7	1	1/3	1/7	1/5	1/3
Current Truck ADT	1/5	3	1	1/7	1/5	1/3
Condition Score	1	7	7	1	7	7
Ride Quality	1/7	5	5	1/7	1	1
Sections that receive most Maintenance	1/7	3	3	1/7	1	1

Figure 4.3. Bryan District Decision Maker Completed Project Selection Matrix

Completing this matrix would follow a thought process of moving down the parameters listed on the left and comparing them with the parameters listed across the top. For example Visual Distress is initially compared with Visual Distress, thus explaining the "1" located in the upper left box of the matrix. Visual Distress is then compared with Current ADT and the decision maker sees Visual Distress as significantly more important than Current ADT, thus explaining the "7" in the second square along the top row. The reciprocal of this, "1/7", is placed in the second square in the first column where Current ADT is compared to Visual Distress and is significantly less important. These comparisons continue until the matrix is complete.

As discussed earlier, the eigenvector calculations associated with solving an *nxn* matrix involves solving a polynomial to the nth degree. Therefore the 6x6 matrix illustrated in Figure 4.3 requires solving a polynomial equation to the 6th degree. Without the help of computational programs, this calculation would be tedious, time consuming, and difficult. The researcher employed Python 2.6 and the Python add-in libraries Numpy and Pylab to aid in the matrix calculations. The Python code for performing the AHP computations is presented in Appendix D.

The consistency calculations associated with the matrix in Figure 4.3 are illustrated in the following calculations:

$$MaxEigenvector = \lambda_{max} = 6.6399$$
$$Consistency\,Index = CI = \frac{\lambda_{max} - n}{n-1} = \frac{6.6399-1}{6-1} = 0.91574$$
$$Random\,Index = RI = 1.24\,(predfined\;for\,a\,6x6\,matrix)$$
$$Consistency\,Ratio = CR = \frac{CI}{RI} = \frac{0.91574}{1.24} = 0.10$$

The CR for the pairwise comparisons from the Bryan district decision maker is 10 percent, the upper allowable limit for the consistency ratio. Since the consistency ratio falls within the acceptable range, the application of AHP can continue. To normalize the maximum eigenvector, the maximum eigenvalues of all six parameters were summed and then each one was divided by this summation. The resulting priority vector will then sum to one and the values associated with each parameter are weights of importance. Table 4.5 displays the maximum eigenvector and the resulting priority vector for the six decision parameters. This priority vector is used in the prioritization method developed to bridge the gap between the PMIS network-level pavement management system and the actual project selection process used by TxDOT's districts (with application to the Bryan district).

Table 4.5. Maximum Eigenvector and Priority Vector for Decision Parameters

Decision Parameter	**Max Eigenvector**	**Priority Vector (Weigths)**
Visual Distress	0.6711	0.3660
Current ADT	0.0546	0.0298
Current Truck ADT	0.0854	0.0466
Condition Score	0.6968	0.3801
Ride Quality	0.1839	0.1003
Section Receiving most Maintenance	0.1417	0.0773
Sum	**1.8334**	**1**

Table 4.5 clearly indicates that Condition Score receives the most weight when considering pavement preservation decisions. This is not a surprising revelation due to the fact that Condition Score is the so called "statewide report card" and based on interviews with district personnel, not just the Bryan district, decision makers are keenly aware that the Commission and legislators use this parameter as a performance measure (especially with respect to the 90 percent good or better goal issued by the Commission).

Condition Score and visual distress account for 75 percent of the decision weight for pavement preservation projects. The remaining 25 percent is split among current ADT at slightly below three percent, current truck ADT at just above four and a half percent, ride quality at approximately 10 percent, and sections receiving the most maintenance at just over 7.5 percent. Finally, it is interesting to note that the priority vector represents a unified 0-to-1 measuring scale for all six parameters (which have varying measurement units).

4.4 RELATIVE IMPORTANCE WITHIN EACH DECISION PARAMETER

The AHP is applied to determine "when" and "how much more or less" important one section is compared to another. For example, when does a section become more important in terms of traffic volume? Is a section with 1,500 vehicles per day equally as important as a section with 4,000 vehicles per day, and how much more important is a section with 15,000 vehicles per day compared with a section that has only 750 vehicles per day? The same questions arise for each one of the decision parameters and represent the third level of the hierarchy in Figure 4.1.

To make these comparisons, each section must be compared to every other section for each decision parameter. Normally the AHP is applied to a fairly small number of competing alternatives, say 15 alternatives. A matrix of this size is easily completed in a short period of time, however to apply the method to a pavement network, the number of comparisons would be quite large and completing the matrix through personnel interviews by individually comparing each section to every other section is not feasible, economical, or reasonable. Case in point, the pavement network used in the study includes the on-system roadways in Robertson, Leon, and Freestone counties in the Bryan district, consisting of 2349 sections. These section versus section pairwise comparisons are made through the use of logic statements, resulting in a 2349 element vector. This vector is the ranking of each section in regard to that specific decision parameter. Ultimately these vectors will have the decision parameter weights applied and carried through to create a 2349 element vector that is the project selection number or ranking of each section based on the research method. By using logic statements to compare each section, there is no further need to test consistency. The AHP uses consistency calculation to ensure that human comparisons do not deviate to a point that makes the comparisons invalid for additional use, however by using logic statements coded in computation tools, consistency can be assumed.

All of the section information regarding each decision parameter must be stratified so that logic statements can be written. These stratifications of the data are illustrated in Table 4.6.

Table 4.6. AHP Weight Associated with Minimum Comparison

AHP Weight	Visual Distress (DN)	Current ADT (veh/day)	Current FM Truck ADT (trucks/day	Current Non-FM Truck ADT (trucks/day)
1	DN = 0.2629	veh/day ≤ 1000	trucks/day ≤ 160	trucks/day ≤ 1225
2	0.2629 < DN ≤ 0.433	NA	NA	NA
3	0.433 < DN ≤ 0.603	1000 < veh/day ≤ 2000	160 < trucks/day ≤ 320	1225 < trucks/day ≤ 2450
4	0.603 < DN ≤ 0.773	NA	NA	NA
5	0.733 < DN ≤ 0.943	2000 < veh/day ≤ 7000	320 < trucks/day ≤ 480	2450 < trucks/day ≤ 3675
6	0.943 < DN ≤ 1.113	NA	NA	NA
7	1.113 < DN ≤ 1.283	7000 < veh/day ≤ 10,000	480 < trucks/day ≤ 640	3675 < trucks/day ≤ 4900
8	1.283 < DN ≤ 1.45	NA	NA	NA
9	1.45 < DN	10,000 < veh/day	640 < trucks/day	4900 < trucks/day
AHP Weight	**Condition Score (CS)**	**FM Ride Quality (IRI)**	**Non-FM Ride Qualtiy (IRI)**	**Maintenance Cost ($)**
1	90 to 100	1 to 119	1 to 59	Cost = $0
2	NA	NA	NA	$0 < Cost ≤ $6000
3	70 to 89	120 to 154	60 to 119	$6000 < Cost ≤ $12,000
4	NA	NA	NA	$12,000 < Cost ≤ $18,000
5	50 to 69	155 to 189	120 to 170	$18,000 < Cost ≤ $24,000
6	NA	NA	NA	$24,000 < Cost ≤ $30,000
7	35 to 49	190 to 220	171 to 220	$30,000 < Cost ≤ $36,000
8	NA	NA	NA	$36,000 < Cost ≤ $42,000
9	1 to 34	221 to 950	221 to 950	$42,000 < Cost

By using the term minimum comparison in Table 4.6, it is meant that this sets the initial AHP weight of a section. For example, if a section has a Condition Score of 40 and is compared to a section with a condition score of 100, the section with a 40 would receive an AHP weight of seven. What is not displayed in Table 4.6 is the weight assigned when a section with a Condition Score of 40 is compared to a section with a Condition Score of 75. This is done with a logic statement by merely subtracting the two sections' weights when each is compared to a minimum, thus receiving the weight in Table 4.6. It is important to note that one must be added to the result of this subtraction to preserve the fact that the AHP begins at one rather than zero.

The visual distress number is a unique parameter in the sense the weights had to be applied to the various distresses considered at the district level and each section must compete against every other section in regards to how important more or less distress was and how did that importance change as multiple distresses were evaluated at the same time. To solve this type of problem, the same hierarchical approach was used as with the project selection number and the AHP was applied to determine a distress number that could be used as the visual distress component. This is discussed in further detail, but before explaining the creation of the distress number the stratification of the other parameters is discussed.

The first point to mention is that ride quality and truck ADT are evaluated differently for the type of roadway. This division was based on a suggestion by the Bryan decision maker and was made using the fact that many of the FM systems with the Bryan district contain a pavement structure that consists of flexible base with a seal coat as the riding surface. The assumption is made that fewer trucks will do more damage to a pavement structure such as this than the same amount on a more extensive pavement design. For ride quality, the basis for the division is that applying a hot-mix asphalt riding surface allows a contractor more control over deviations in the surface and thus roughness should be distinguished differently between the two. The district holds to this thought for the application of monetary penalties, at a higher IRI value for roadways having only a surface treatment as the riding surface. The further stratification of ride quality was done based on the ride specification in the Standard Specifications and additional TxDOT guidance on smoothness defining an IRI of 1 to 59 as very smooth, 60 to 119 as smooth, 120 to 170 as medium rough, 171-220 as rough, and 221-950 as very rough. The Bryan decision maker had never thought of truck ADT in a sense of when to determine if a section is more or less important. Therefore the truck ADT breakdown was based on the data available within the analyzed network. The maximum AHP weight of nine was assigned to all truck volumes in the highest two percent. The further assignment of weights proceeded linearly by placing the truck volume in equal bins for weight assignment. This assignment of weight based on truck ADT could be adjusted based on the damage caused by trucks to a certain pavement design if the information were readily available and trustworthy. This type of flexibility within the AHP makes it attractive for the decision making process, particularly with the knowledge that these parameters will change as more information becomes available or as research warrants.

Current ADT was broken down based on information from the Bryan decision maker as to how traffic is currently viewed and handled for preservation projects. Condition Score was stratified based on the current descriptions used by TxDOT to describe scores. Lastly, maintenance costs were placed in equal bins and a linearity of importance was assumed to the point that a nine was assigned when the cost exceeded 98 percent of the costs experienced by other sections. It is hard to verify the validity of the assumption, but the point should be made that the new method is trying to capture how decision makers currently make decisions and intuitively it can be stated that if a section has more maintenance money spent on it than another section it is more important from a preservation standpoint and the linear assumption captures this thought. The intermediate AHP values were used for maintenance cost to close the gaps between dollar amounts, eliminating broad cost amounts receiving equal weight.

4.5 RELATIVE IMPORTANCE ACROSS DISTRESSES

The need to include an accurate portrayal of distresses within a section of pavement has been discussed at length, but how to frame the various distresses and respective densities as matter of importance has not. As discussed in Section 3, the research uses three years of distress data in order to more accurately account for routine maintenance practices within TxDOT. To determine how the multiple distresses should be aggregated, the researcher had to determine how important one distress is compared to another distress. To create a uniform method, the best way to determine importance is to apply the AHP to distresses in the same way that it was applied to decision parameters, using the Bryan decision maker's feedback. Calculation of a distress number was performed in a hierarchical way as represented in Figure 4.4.

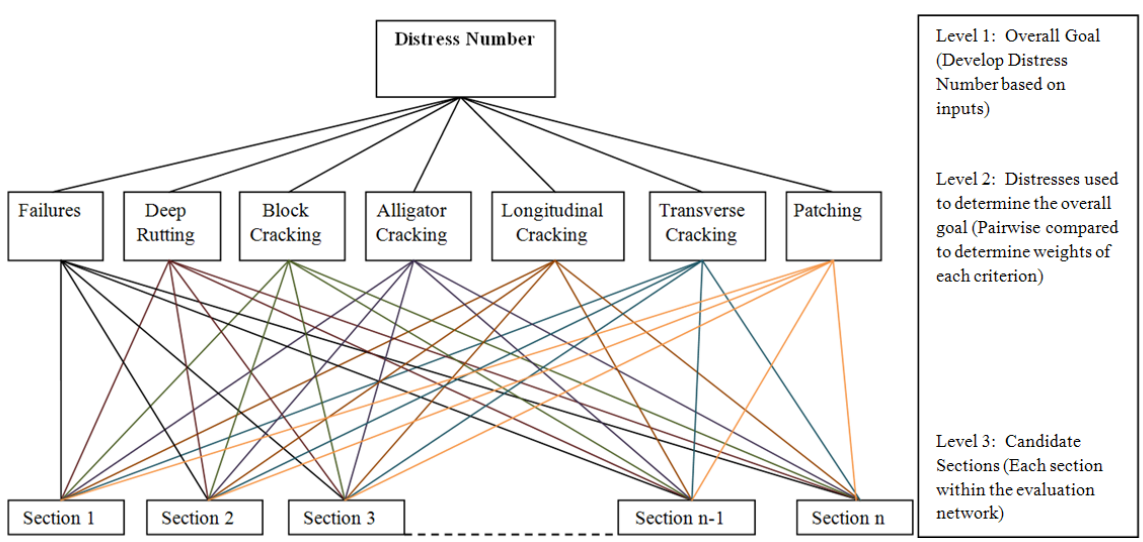


Figure 4.4. Distress Hierarchy

The distresses at level two of the hierarchy are currently used in the calculation of the Distress Score within PMIS. The thesis research differs from the Distress Score in the sense that it seeks to find the relative importance of each of these distresses from the perspective of the Bryan district. The Bryan decision maker was provided a 7x7 matrix with these distresses to perform a pairwise comparison. From these comparisons, the relative weights associated with each distress can be determined using the eigenvector calculations described earlier for the decision parameters. Figure 4.5 illustrates the completed matrix and Table 4.7 illustrates the weights associated with each distress.

	Failures	**Deep Rutting**	**Block Cracking**	**Alligator Cracking**	**Longitudinal Cracking**	**Transverse Cracking**	**Patching**
Failures	1	5	9	5	7	9	5
Deep Rutting	1/5	1	7	3	5	9	3
Block Cracking	1/9	1/7	1	1/3	1/3	1	1/7
Alligator Cracking	1/5	1/3	3	1	5	5	3
Longitudinal Cracking	1/7	1/5	3	1/5	1	3	1/5
Transverse Cracking	1/9	1/9	1	1/5	1/3	1	1/5
Patching	1/5	1/3	7	1/3	5	5	1

Figure 4.5. Bryan District Decision Maker Completed Distress Matrix

Table 4.7. Maximum Eigenvector and Priority Vector for Distress Types

Distress Type	**Max Eigenvector**	**Priority Vector**
Failures	0.8484	0.4488
Deep Rutting	0.4023	0.2128
Block Cracking	0.0500	0.0264
Alligator Cracking	0.2537	0.1342
Longitudinal Cracking	0.0854	0.0452
Transverse Cracking	0.0455	0.0241
Patching	0.2051	0.1085
Sum	**1.8905**	**1**

The consistency calculations to determine if the comparisons provided by the decision maker are valid are provided below.

$$\lambda_{max} = 7.7924$$

$$CI = \frac{7.7924 - 7}{7 - 1} = 0.1321$$

$$RI = 1.32\,(\textit{predefined for a}\ 7x7\ \textit{matrix})$$

$$CR = \frac{0.1321}{1.32} = 0.1001$$

Fortunately the consistency ratio (CR) for the seven-by-seven matrix is almost exactly 10 percent, an acceptable level in the AHP. Based on these calculations, the researcher decided to move forward using the seven-by-seven distress matrix illustrated in Figure 4.5. From Table 4.7 it is clear that Failures are by far the distress that receives the most consideration when making pavement preservation decisions, followed by Deep Rutting, Alligator Cracking, and Patching. Block cracking, Longitudinal Cracking, and Transverse Cracking receive little consideration when making these types of decisions. In fact, there was no block cracking recoded in any of the years evaluated for the three county network used in the study. For this reason, Block Cracking will not be discussed further.

The development of these weights will eventually help the answer not only the question as to whether or not Failures are more important than Alligator Cracking, but is a section with two Failures and 50 feet of Alligator Cracking more important than a section with 25 percent Alligator Cracking and 15 percent Patching? Whichever one is more important the method will also indicate a magnitude of how much more important and if there are sections of varying importance between the two. However, to fully answer questions such as these each section must compete against every other section in regards to each of the distress types illustrated in Table 4.4. In summary, the AHP must be applied to Failures, Deep Rutting, Block Cracking, and so on just as it was applied to current ADT, truck ADT, and the other decision parameters. This application can eventually be aggregated together to create the visual distress parameter for each section that will be used to finalize the creation of a project selection number. Prior to completing this action, the distress information must be divided in such a way that logic statements can be constructed to perform the 2349 x 2349 comparison. The method used to accomplish the stratification of the distress information is discussed in the next section.

4.6 RELATIVE IMPORTANCE WITHIN EACH DISTRESS TYPE

Table 4.8 shows the AHP weight assignment to various distress densities.

Table 4.8. AHP Distress Weight Associated with Minimum Comparison

AHP Weight	Failures (EA)	Deep Rutting (%)	Alligator Cracking (%)	Longitudinal Cracking (ft)	Transverse Cracking (EA)	Patching (%)
1	0	0% to 4%	0% to 2%	0' to 25'	0 to 2	0% ≤ Patch ≤ 3%
2	1	5% and 6%	3%	26' to 50'	3	3% < Patch ≤ 7%
3	2	7%	4%	51' to 75'	4	NA
4	NA	8%	5%	NA	5	7% < Patch ≤ 11%
5	NA	9%	6%	76' to 100'	6	11% < Patch ≤ 15%
6	NA	10%	7%	101' to 125'	NA	15% ≤ Patch ≤ 22%
7	3	11%	8%	126' to 150'	7	22% < Patch ≤ 35%
8	4	12%	9% and 10%	151' to 175'	8	35% < Patch ≤ 44%
9	≥ 5	≥ 13%	≥ 11%	≥ 176'	9	44% < Patch

Again, the AHP weight in Table 4.8 is associated with comparing a section to the minimum, or least important, section. After the establishment of this minimum comparison, the sections can be compared using the AHP weights to determine importance when one of the two sections has the least important value. Before moving on to the creation of the actual distress number, it is valuable to briefly describe how stratifications in the distress densities were achieved.

The challenge with applying the AHP to failures is how can the distresses be compared to determine if one section is more important than another section and how should the magnitude of importance increase or decrease? Common sense states that as distress density increases, the importance to perform preservation work on the section also increases. In short, a section that has four Failures is more important than a section with only two Failures, but how much more? This question not only needs to be answered, but the question as to what level of distress density does a section become drastically more important must be answered. The research is confined by the pre-established weighting scheme with the AHP, therefore the researcher decided to establish a system to define the upper limit where the AHP weight of nine can be assigned.

The upper limit is defined based on actual distress density within the three counties of the study. The assumption was made that there is an unacceptable level of all distresses that the district simply will not allow a section of roadway to reach without performing some type of maintenance. Any distress above this point could be considered drastically more important than a section with none of that particular distress manifested. This assumption would allow the assignment of nine to a distress density value. The researcher set this upper limit as the point at which 98 percent of distress density was at or below.

To fill in the rest of the gaps regarding AHP weight and distress density, PMIS contains curves that describe how distresses affect the Distress Score and subsequently the Condition Score for a section of pavement. These curves are often termed utility curves for the respective distress under consideration, however while the AHP method being employed does not use or seek to use utility, these curves can help determine how important varying degrees of distress density are considered.

The AHP weight and the utility curves are obviously not on the same scale; however weights can be assigned to the increase in distress density in such a way that a curve can be created for the AHP method that matches the shape of the utility curve. By doing this, the method will follow the current thought used by TxDOT and in PMIS to determine how distresses affect a section of pavement. It is important to note that the researcher's method could be adjusted to match new curves created in the event additional research was performed and required the current curves to be adjusted to more accurately match how research indicates distresses affect a pavement structure. The main point of this is to make sure the weights from the AHP accurately reflect the drops and magnitude of drops caused by the respective distresses as illustrated through the utility curves. The comparison between the utility curve for failures, in PMIS, and the curve created for the AHP weight is shown in Figures 4.6.

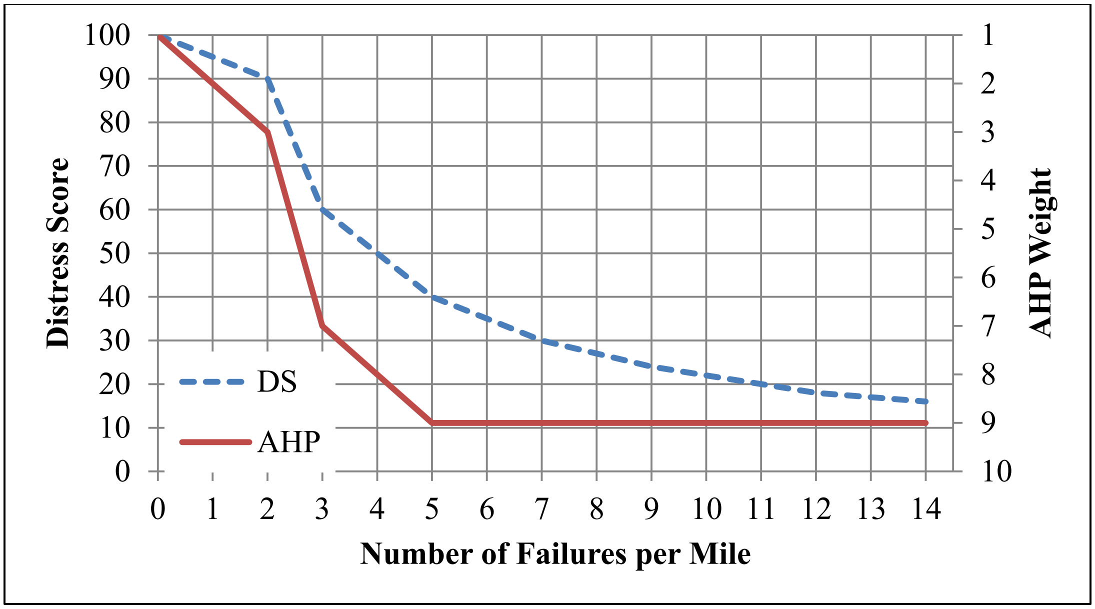


Figure 4.6. Curve Comparison of Number of Failures vs. Distress Score and AHP Weight

To describe the curves in Figure 4.6, the easiest place to start is at the top where zero Failures results in a Distress Score of 100 and an AHP weight of one. To continue the comparison, the next place to look is where an AHP weight of nine is assigned, for Failures this is at five or more. It is easy to see that the actual utility curve has not "bottomed-out" at this point, but from previous analysis of the network, it is known that 98 percent of the sections have fewer than five Failures, creating the point to assign the maximum AHP weight of nine. To connect the dots in between these two points, the researcher followed the shape of the utility curve, matching the linear drop between zero and two Failures and between three and five Failures. From Table 4.8, it is clear that the linear drop from zero to two failures is from a Distress Score of 100 to 90, but at three failures the Distress Score drops to 60. The linear drop from 100 to 90 is represented by ascending AHP weights of one, two, and three, while the significant drop from a Distress Score of 90 to 60 as the number of Failures increases from two to three is represented by an increase in the AHP weight from three at two Failures to seven at three Failures. The linearity in the AHP continues from three to five Failures as the weight linearly increases from seven to nine, just as the Distress Score descended linearly from 60 to 40. The fact that the AHP begins at one rather than zero and that the maximum AHP weight of nine is set based on the distress density on the system and not at the point where the actual utility curve reaches its minimum makes the transition between the two measuring scales somewhat difficult, but it provides the best way to make the comparison over 2349 sections and can be adjusted based on the outcome of the method development. Using the breakdowns created through this method, the logic statements can be written and the priority vectors can be determined for each of the distresses. The remainders of the curve comparisons for other distresses considered are available in Figures 4.7 to 4.11.

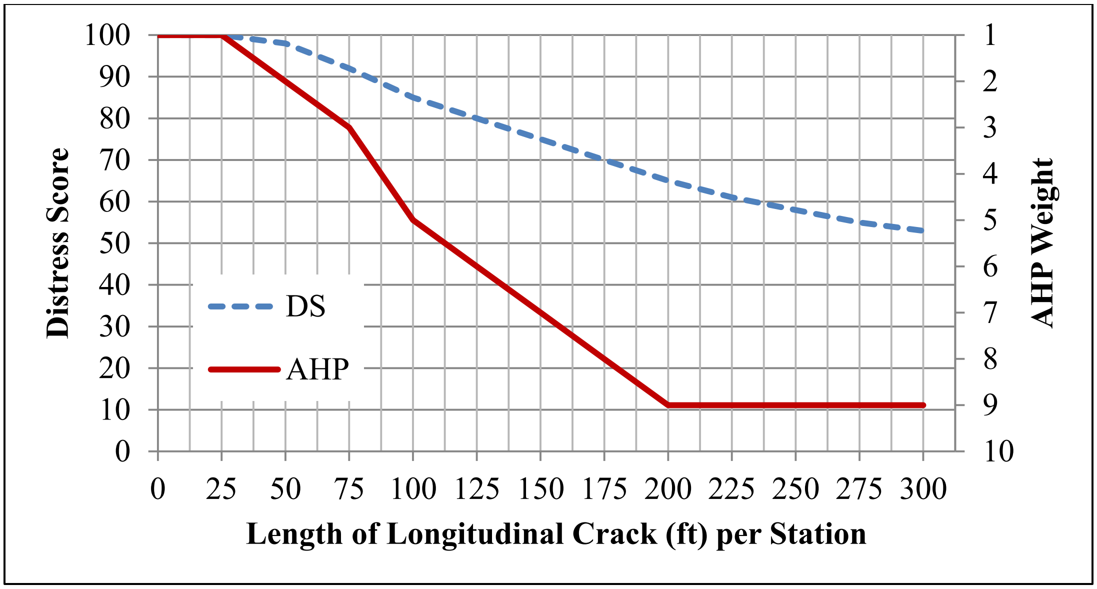


Figure 4.7. Curve Comparison of Longitudinal Cracking vs. Distress Score and AHP Weight

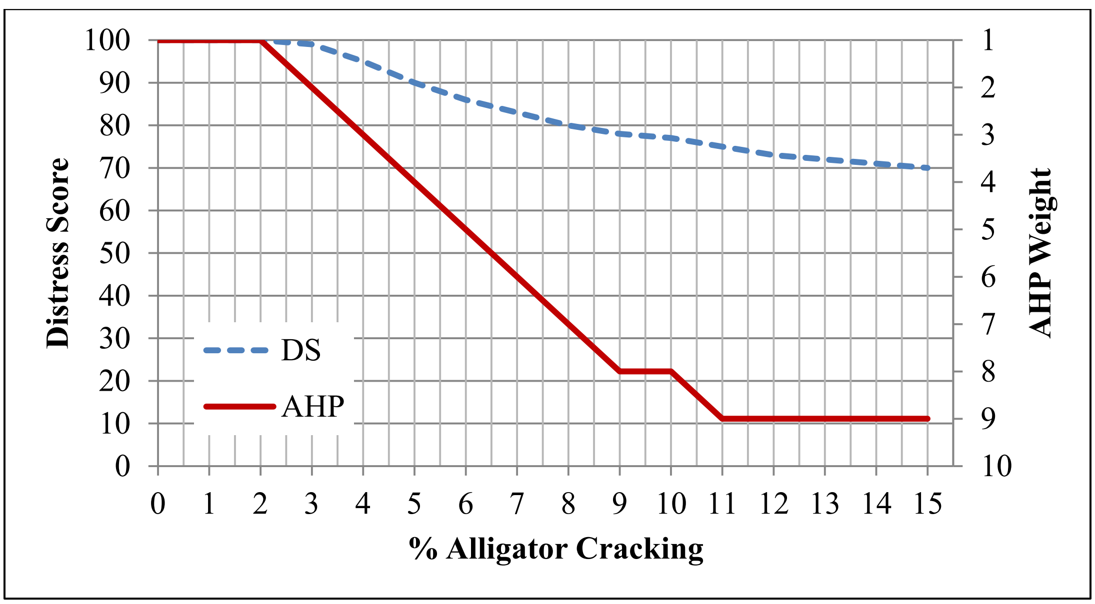


Figure 4.8. Curve Comparison of Alligator Cracking vs. Distress Score and AHP Weight

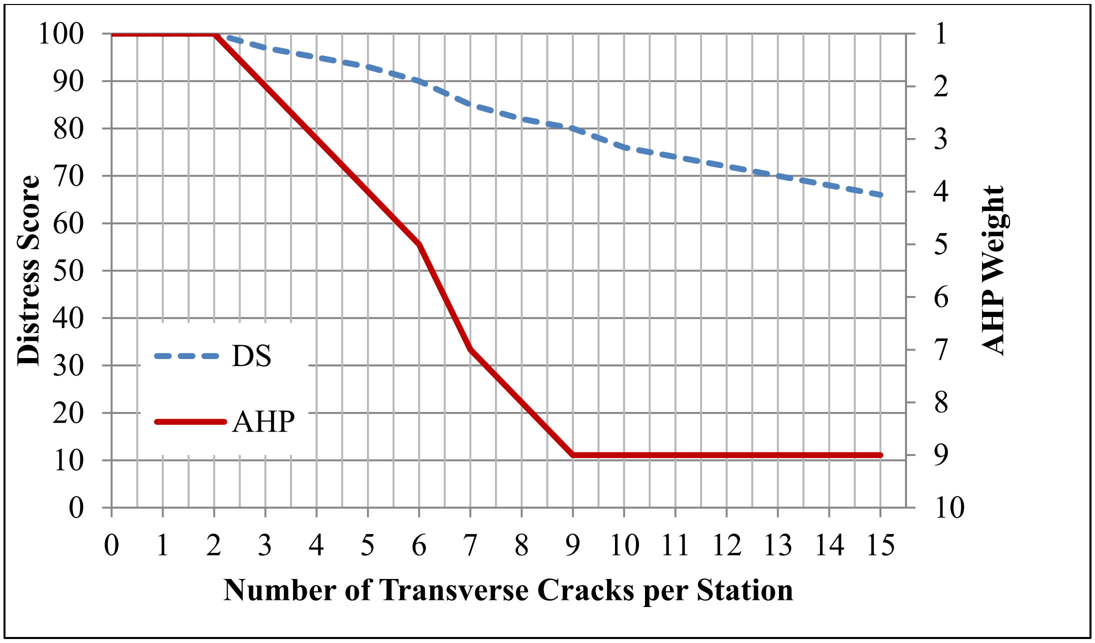


Figure 4.9. Curve Comparison of Transverse Cracking vs. Distress Score and AHP Weight

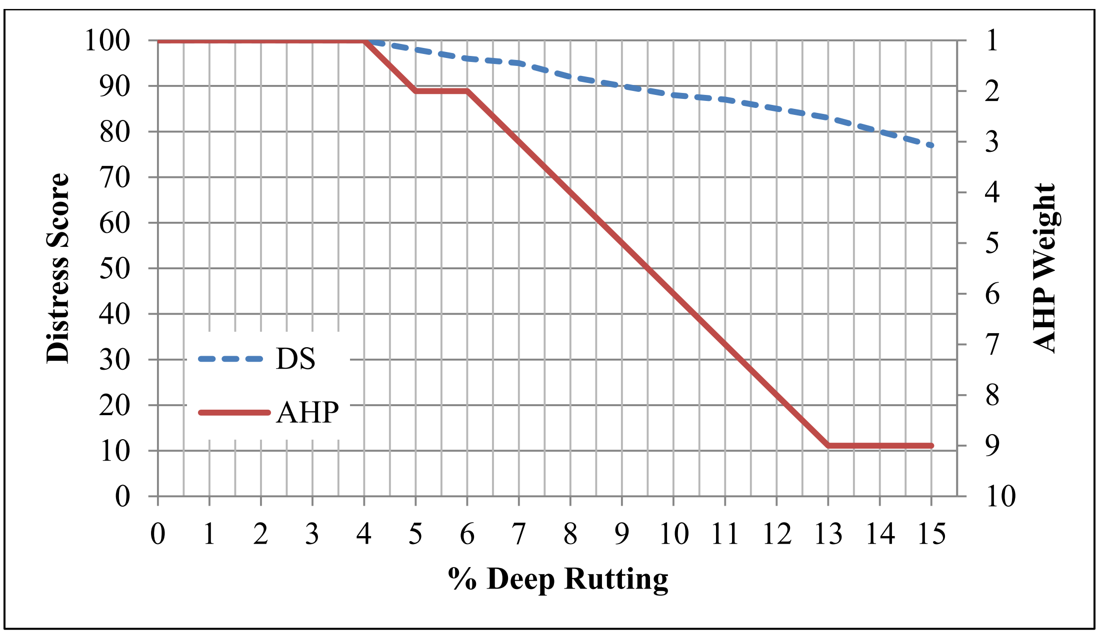


Figure 4.10. Curve Comparison of Deep Rutting vs. Distress Score and AHP Weight

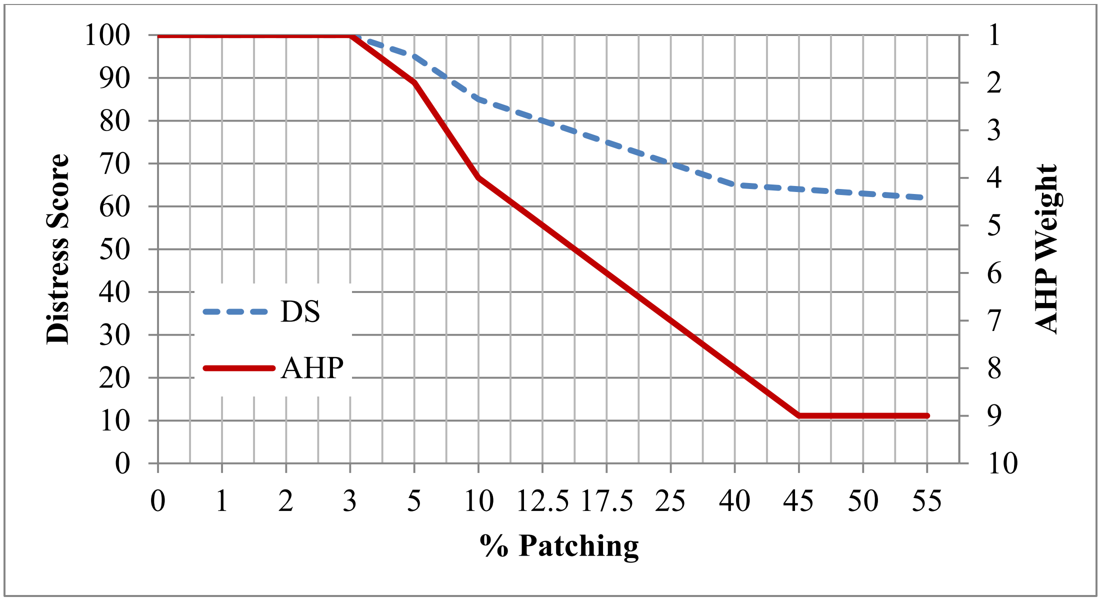


Figure 4.11. Curve Comparison of Patching vs. Distress Score and AHP Weight

The logic statements developed from curves above allowed for the application of the AHP to the network within the study and creates priority vectors for each of the distress types. In summary, the method created a ranking of importance independently for each section in regard to all distress types. The combination of these weight vectors with the weights developed from the application of the AHP at level two of the hierarchy in Figure 4.4 and the aggregation of all components together results in the creation of the distress number to be used to finalize the creation of the project selection number. This is further discussed in the following section.

4.7 CREATION OF VISUAL DISTRESS NUMBER AND PROJECT SELECTION NUMBER

The next step in the process is to take the results from the competitions performed by each section for all distress and decision criteria and begin aggregating information to create a final index that can be used to prioritize pavement sections.

4.7.1 Aggregation of Distress Priority Vectors

With a priority vector for each of the distresses shown at level two of the hierarchy illustrated in Figure 4.4, all components in the hierarchy are complete and a distress number for each of the 2349 sections can be created. The calculation of the distress number follows the calculations presented below.

$$DN_n = \sum_{d=1}^{k} w_d * pz_n$$

where,

$DN_n = \textit{the distress number for any section within the evaluation network}$

$d = \textit{distress types considered in the decision}\left(k = 7 \textit{ in the current study}\right)$

$w_d = \textit{weight associated with a particular distress}$

$pz_n = \textit{priority number associated with any section within the evaluation network}$

Sorting the pavement sections based on distress numbers created indicates that the largest distress number within the three county network is 2.4502, located on FM 485 from Reference Marker 606+00.5 to 606+01.0. Multiple sections within the network received ones for every distress type when creating the priority vectors with the AHP. Because the AHP begins with a one and not a zero, there is a number associated with these sections that all received ones during the AHP process. This number is 0.2629, but it is important to note that it will not always be this number; it varies depending on the size of the network which changes the calculations of the eigenvectors and eigenvalues.

This distress number will become the visual distress parameter used in the application of the AHP to the decision parameters, but before the project selection number can be created, these visual distress numbers must be stratified so that the AHP can be applied another time to create a priority vector that can be used in the project selection number creation. Because this distress number is a new creation from the current research efforts, there is no defined way to set importance, therefore to continue the researcher established the lower limit where an AHP weight of one would be assigned and an upper limit where the AHP weight of nine would be assigned. The lower limit was set at 0.2629, the perfect distress section as described above. The AHP weight of one only applies to sections with this distress number based on the assumption that if any section was exhibiting enough distress to register a distress number after the application of the AHP it was at least minimally more important than sections that resulted in the minimum number. To set the upper limit, the researcher continued to use the 98 percentile limit and for distress numbers that value was 1.45. Therefore, any section with a distress number greater than or equal to 1.45 received an AHP weight of nine when comparing it to a section with a distress number of 0.2629. To continue to show that importance increases as the distress number increases, the researcher assumed that importance grew linearly. Between 0.2629 and 1.45, all values of the AHP were used and the distress numbers were broken down into linear bins to assign the appropriate weight. This breakdown was provided with the breakdown of all other decision parameters in Table 4.6. With a weight vector created for the final decision parameter, the method can continue with the development of the project selection number.

4.7.2 Aggregation of Decision Parameter Priority Vectors

A competition on a section-by-section basis has now taken place 12 times. The AHP has been applied to all six decision parameters and all distresses (block cracking not included) associated with the creation of the project selection number. The final step in the process is to apply the weights for each decision parameter to each of the priority vectors and sum across to create the project selection number for each section within the network. This calculation occurs in the same way it did with the distresses during the creation of the distress number and is represented with the following equation:

$$PN_n = \sum_{p=1}^{k} w_p * pz_n$$

where,

$PN_n = \text{the project selection number for any section within the evaluation network}$

$p = \text{decision parameter considered in the decision} \left(k = 6 \text{ in the current study} \right)$

$w_p = \text{weight associated with a particular parameter}$

$pz_n = \text{priority number associated with any section within the evaluation network}$

To simplify the information created, the researcher forced all sections with a perfect distress number to zero, assuming pavement preservation work is not required on sections with no distress. After all calculations, 1377 of the 2349 sections within Freestone, Leon, and Robertson counties have a project selection number greater than zero. The way the method works is that sections more in need of preservation work have a higher project selection number with the worst section in the network having a project selection number of 2.0141, located on FM 1119 from Reference Marker 0368+00.0 to 0368+00.5. This value is not the highest possible value the method could generate, in fact theoretically there could be a section that received all nines in the AHP compared to every other section, but this event is almost impossible, especially on a network consisting of 2349 sections. Another possibility is that the highest volume roadway with the highest truck traffic consisting of the worst ride quality and Condition Score also has the worst visual distress number and has had more maintenance money spent on it than any other section in the network. A section such as this would receive a nine in every category when compared to the minimum event, but not every other section in the network would receive ones, therefore this type of maximum project number is plausible, but not extremely realistic. In reality, no single section will solely carry the highest value in every category in a network of any significant size and in fact, many sections will have the same value across many parameters, creating more parity among sections. The analogy of competition can be continued in this train of thought by thinking of a baseball league. The odds of any one team being drastically better than the others at pitching, hitting, running, and fielding is unlikely and in fact a different team is probably the best in each one of these categories respectively and it also likely that there are multiple teams that are equally as good. The team that often comes out on top is the one that is probably the best in one of these categories and near the top in the others and when all of the components are aggregated together, that team usually wins. This analogy captures the thought process behind the aggregation of these components to create a project selection number.

For practical purposes, the maximum number was calculated by taking the maximum possible number from each priority vector, multiplying it by the appropriate weight and summing across. The practical maximum for the network evaluated was 2.28.

The 1377 sections with a project selection number were sorted from highest to lowest and a rank was attached to each section. Observing the sorted and ranked sections offers some insight to the drivers of the newly created method. The top 11 project numbers have a maximum distress number of 2.5348, indicating that a section with severe distress will likely create a high project selection number, a fact that should occur because the research is concerned with pavement preservation projects. The section ranked 147th also has this distress number, indicating that all sections within the district with the highest distress number are within the top 11 percent of project selection numbers, but it also indicates that other parameters can affect the decision, a fact the method was hoping to capture.

The AHP has provided the basis for developing a project selection number that accounts for many variables and does so in a way that assigns realistic weights to the decision parameters in the same way that districts view these components. However, to truly test the project selection number, pavement preservation projects must be selected and evaluated against actual projects performed to determine if the created method matches reality. To make this move, the research must move beyond section related information, which is the location where the current research has been stationed, and into the actual selection of projects involving the selection of multiple sections, further bridging the gap between network and project-level pavement management.

4.8 PROJECT SELECTION

TxDOT has no rules that define the length of a preservation project; it is something that is left up to the individual districts to determine. To begin to determine how long the preservation projects should be, the researcher returned to the data to determine what was actually being done in the field. For this exercise, the researcher did not limit the scope to the three counties; rather construction projects for the entire district for FY 2007, FY 2008, and FY 2009 were evaluated. Projects evaluated include those with a preservation activity heavier than seal coat and consist of nine projects from FY 2007, four projects from FY 2008, and 14 projects from FY 2009. These projects and their respective costs and lengths are shown in Table 4.9.

Table 4.9. Bryan District Project Table with Lengths

FY	HWY	Rd Bed	BRM	ERM	Type	Cost (million)	Length (miles)	County Name
2007	FM 1155	K	0432+01.5	0434+01.0	Grading, Struct., Base, Surf	$1.110	1.4	
2007	FM 1644	K	0402+00.5	0404+00.5	Grading, Struct., Base, Surf	$0.774	2.2	Robertson
2007	FM 2447	K	0444+01.5	0453+00.0	Grading, Struct., Base, Surf	$1.719	6.8	
2007	FM 362	K	0424+00.0	0428+01.0	Restore	$2.255	5.0	
2007	FM 485	K	0604+00.0	0610+00.0	Restore	$0.490	5.9	Robertson
2007	FM 489	K	0624+00.0	0631+00.0	Restore	$2.035	7.0	Freestone
2007	FM 60	K	0608+00.0	0614-01.3	Grading, Struct., Base, Surf	$1.870	4.3	
2007	FM 912	K	0628+00.0	0631+00.0	Grading, Struct., Base, Surf	$2.252	2.8	
2007	US 84	K	0750+00.0	0758+00.0	Grading, Struct., Base, Surf	$3.825	7.4	Freestone
2008	FM 2562	K	0414+00.0	0418+00.0	Grading, Struct., Base, Surf	$1.443	4.0	
2008	FM 39	K	0388+01.0	0396+02.0	Grading, Struct., Base, Surf	$3.424	9.0	Leon
2008	SH 7	K	0624+00.0	0624+01.5	Grading, Struct., Base, Surf	$1.216	1.5	Leon
2008	US 190	K	0744+00.0	0748+01.5	Grading, Struct., Base, Surf	$0.473	5.5	
2009	FM 1451	K	0342+00.5	0349+00.0	Grading, Struct., Base, Surf	$1.854	6.0	Freestone
2009	FM 1644	K	0384+00.0	0394+01.5	Restore	$3.049	11.0	Robertson
2009	FM 1179	K	0410+01.5	0412+00.8	Overlay	$0.420	1.3	
2009	FM 2154	K	0618+01.0	0620+00.5	Rehab	$1.003	1.2	
2009	FM 247	K	0392+00.5	0398+00.0	Grading, Struct., Base, Surf	$2.814	6.0	
2009	FM 39	K	0368+00.0	0368+00.5	Rehab	$0.374	0.5	
2009	FM 488	K	0318+00.0	0322+01.0	Grading, Struct., Base, Surf	$1.218	5.0	Freestone
2009	FM 542	K	0366+00.0	0368+00.2	Restore	$0.747	2.7	Leon
2009	FM 60	K	0632+01.0	0632+01.5	Overlay	$0.408	0.5	
2009	FM 60	K	0634+01.1	0634+01.6	Overlay	$0.235	0.5	
2009	FM 80	K	0354-00.3	0360+01.5	Restore	$2.003	7.8	Freestone
2009	FM 80	K	0346-01.6	0352+01.6	Grading, Struct., Base, Surf	$2.547	9.0	Freestone
2009	IH 45	L&R	0167+00.5	0174+00.5	Overlay	$1.751	7.0	Leon
2009	SH 6	K	0610+01.6	0616+01.0	Rehab	$2.117	7.0	

The average cost of the projects in Table 4.9 is $1.61 million and has an average length of 4.8 miles. The standard deviation for the projects is $0.99 million and 3.0 miles regarding cost and length. Figure 4.12 describes the lengths of projects within the Bryan district, with projects grouped in one mile lengths. Table 4.9 also justifies the use of Freestone, Leon, and Robertson counties for further evaluation because seven of the 14 projects in FY 2009 occur in these counties, but more importantly, 75 percent of the length receiving preservation work occurred in these three counties.

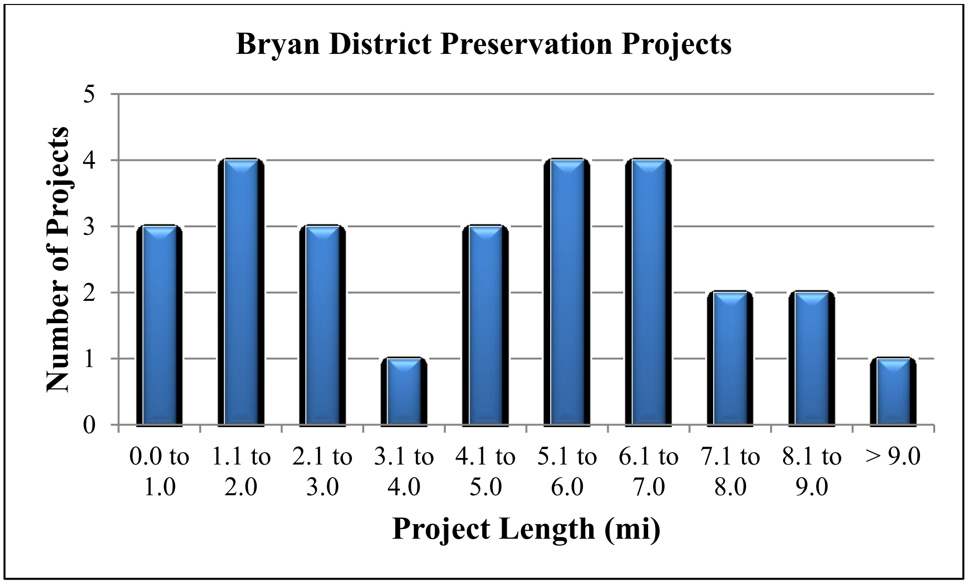


Figure 4.12. Bryan District Project Lengths Histogram

With the range of project lengths widely varied, the researcher approached the Bryan district decision maker to see if the district had a length in mind when creating preservation projects. The decision maker responded that the district tries to achieve projects of at least two miles in length in regards to pavement preservation. When informed the average over FY 2007, 2008, and 2009 was 4.8 miles, the decision maker suggested that the reason it was more than twice the length of the predefined 2-mile length had to do with the American Recovery and Reinvestment Act (ARRA) that provide significant federal funds to "shovel" ready projects. With the extra funds, the district was able to take a more proactive approach and apply preservation treatments to additional miles that might not have originally received work. This appears to be the case as nine of the 14 projects in FY 2009, the year the ARRA funds were available, were over two miles in length and eight of those nine were longer than five miles.

Therefore to move forward with the creation of projects, the researcher will evaluate enough sections to create at least a two mile project and will continue to aggregate sections in a logical way, thus creating projects longer than two miles.

To perform this operation, a logic statement was written to “drive” through the sections and sum project numbers. Because the typical section length is ½-mile, project sections were summed across four sections and the four section project numbers were sorted from largest to smallest with the largest indicating the most important pavement preservation project. “Driving” down the road so to speak creates 1884 four-section summations above zero. The largest summation across four sections equaled 7.59 and occurred on FM 488 from 0320+00.5 to 0322+00.5. The next two summations are also located along FM 488 and actually include sections from the first four section summation and adjacent sections. Based on this initial information about project creation, it appears obvious that preservation projects can be created that are longer than two miles in length.

To further combine sections to create projects, the researcher isolated four section summations that resulted in an average project number over four. The goal was to determine how many feasible projects were contained within this deeper evaluation to see if the method was finding projects that were actually performed within the three counties. Evaluating the possible projects with an average project number over four resulted in a list of 24 possible pavement preservation projects. These projects are presented in Table 4.10 in descending order of average project number of the four sections.

Table 4.10. List of Possible Pavement Preservation Projects

HWY	BRM	ERM	Length (mi)	Max PN	Avg. PN	# of 4-Section Sum.	County Name
FM 488	0318+00.0	0323+00.5	5.5	7.25	6.52	8	Freestone
FM 1451	0344+00.5	0349+00.0	4.5	6.98	5.99	6	Freestone
FM 1644	0389+00.0	0396+00.0	7.0	6.76	5.51	11	Robertson
IH 45 A	0186+00.2	0190+00.0	3.8	6.67	5.46	5	Freestone
FM 485	0605+00.5	0610+00.0	4.5	5.72	4.99	6	Robertson
FM 1848	0351+00.4	0354+00.2	2.8	5.5	4.95	3	Leon
FM 3	0380+00.0	0382+00.5	2.5	5.36	4.94	2	Leon
FM 2547	0331+00.5	0335+00.0	3.5	5.15	4.71	4	Freestone
FM 416	0625+00.3	0627+00.0	1.7	4.64	4.64	1	Freestone
FM 80	0373+00.0	0376+00.7	3.2	4.93	4.61	4	Freestone
FM 2293	0607+00.0	0610+00.0	3.0	4.73	4.54	3	Robertson
SH 75 K	0387+00.0	0389+00.5	2.5	4.4	4.29	2	Leon
US 190 K	0662+00.0	0665+00.5	3.5	4.32	4.29	4	Robertson
FM 80	0351+00.0	0354+00.0	3.0	4.35	4.27	3	Freestone
FM 416	0628+00.5	0632+00.2	3.7	4.37	4.25	5	Freestone
FM 2485	0378+00.0	0380+00.0	2.0	4.25	4.25	1	Leon
FM 488	0332+00.5	0335+00.5	3.0	4.4	4.18	3	Freestone
FM 1940	0624+00.5	0626+00.5	2.0	4.11	4.11	1	Robertson
FM 979	0614+00.7	0616+00.5	1.8	4.11	4.11	1	Robertson
FM 46	0605+00.0	0607+00.0	2.0	4.05	4.05	1	Robertson
FM 27	0618+00.0	0620+00.0	2.0	4.02	4.02	1	Freestone
US 190 K	0657+00.0	0659+00.0	2.4	4.02	4.02	1	Robertson
FM 2777	0342+00.0	0344+00.0	2.0	4.01	4.01	1	Freestone
IH 45 X	0194+00.5	0196+00.5	2.0	4.01	4.01	1	Freestone

The question now becomes whether or not the method identified actual projects performed by the district within these counties. Fortunately the top three projects identified in Table 4.10 had a pavement preservation project let for construction within the limits during FY 2009. Consulting Table 4.9, one can see that a $1.2 million grading/structure/base/surface project was let on FM 488, the highest priority section. The method created actually identified an additional ½-mile that should receive work, but the agreement between the method and reality is promising. FM 1451, the second ranked project from Table 4.10 had a $1.9 million project let over six miles, including the limits identified by the research method. The actual project let was slightly longer than that identified by the method; however the continued agreement between reality and the created method is important. The third project identified by the research method includes limits that are contained within an 11 mile, $3 million restoration project, let on FM 1644 in FY 2009. Again, the method did not identify 100 percent of the project, but a large portion of what was let for construction was identified by the method.

Another important "find" by the research method is FM 485, the fifth ranked project in Table 4.10. This section of FM 485 did not have a project let on it during FY 2009; however there was a 5.9 mile restoration project let during FY 2007 that covered the limits identified by the method. The reason this section was identified by the method is because the worst distress over the last three years is used in the evaluation which found information for this section of roadway prior to the restoration project. This information came from the FY 2006 and FY 2007 ratings prior to construction. The distress information is nonexistent for FY 2008 because the project was under construction to repair what has been identified by the research method. The identification of this section again speaks to the validity of the method.

Table 4.11 provides a further glimpse into district decision making and further validates the newly created project selection and prioritization. Of the 20 projects in Table 4.11, the Bryan district has made decisions to provide a known preservation action on 15. The initial focus was on Category 1 expenditures, agreeing with the projects ranked first, second, third, fifth, and 14th. This information was available at the beginning of the study; however further information from the Bryan decision maker showed that projects ranked fourth and 18th have had construction projects let with Category 1 funds since FY 2009 letting. Projects ranked sixth, seventh, eighth, 11th, 15th, and 17th have all had preservation work performed through routine maintenance contracts. Lastly, projects ranked ninth and 10th are being maintained with TxDOT in-house forces and the district is aware of the preservation needs present within the selected project. The five projects with unknown actions do not necessarily mean that the district is not working on those sections or is not preparing a project for those sections; it only means the information was not available to make any definite determination.

Table 4.11. Projects Selected Compared with District Decisions

Rank	HWY	BRM	ERM	Length (mi)	District Action
1	FM 488	0318+00.0	0323+00.5	5.5	Grading, Structure, Base, Surface Project Let in FY 2009
2	FM 1451	0344+00.5	0349+00.0	4.5	Grading, Structure, Base, Surface Project Let in FY 2009
3	FM 1644	0389+00.0	0396+00.0	7	Restoration Project Let in FY 2009
4	IH 45 A	0186+00.2	0190+00.0	3.8	Contracted Rehab
5	FM 485	0605+00.5	0610+00.0	4.5	Restoration Project Let in FY 2007 - No data available in subsequent years, thus it sees what led to the FY 2007 project
6	FM 1848	0351+00.4	0354+00.2	2.8	Routine Maintenance Contract
7	FM 3	0380+00.0	0382+00.5	2.5	Routine Maintenance Contract
8	FM 2547	0331+00.5	0335+00.0	3.5	Contracted RMC Rehab
9	FM 416	0625+00.3	0627+00.0	1.7	In House Maintenance Forces
10	FM 80	0373+00.0	0376+00.7	3.2	In House Maintenance Forces
11	FM 2293	0607+00.0	0610+00.0	3	Routine Maintenance Contract (FY 2007), then Seal Coat FY 2009
12	SH 75 K	0387+00.0	0389+00.5	2.5	Unknown
13	US 190 K	0662+00.0	0665+00.5	3.5	Unknown
14	FM 80	0351+00.0	0354+00.0	3	Grading, Structure, Base, Surface Project Let in FY 2009
15	FM 416	0628+00.5	0632+00.2	3.7	Routine Maintenance Contract
16	FM 2485	0378+00.0	0380+00.0	2	Unknown
17	FM 488	0332+00.5	0335+00.5	3	Routine Maintenance Contract
18	FM 1940	0624+00.5	0626+00.5	2	In House Maintenance with Rehab let in Nov. 2010
19	FM 979	0614+00.7	0616+00.5	1.8	Unknown
20	FM 46	0605+00.0	0607+00.0	2	Unknown

Overall, the method created matches at least 75 percent of district decisions regarding pavement preservation and improvement, but it should be noted that these preservation decisions are not solely confined to Category 1 funding. Figure 4.13 provides a map of the projects ranked 1 through 20 by the newly developed method. A map this easy to read will also help decision makers decide where to use in-house forces and know how far the projects are located from the maintenance office. In summary, the method creates a list of projects that best describes the preservation needs from the district's perspective. This map helps the district make decisions regarding the allocation of not only Category 1 funds, but the use of routine maintenance contracts and TxDOT maintenance forces. These decisions can be made with information currently available that describes the entire network, highlighting the fact that the research method helps fill the current gap between network and project-level pavement management.

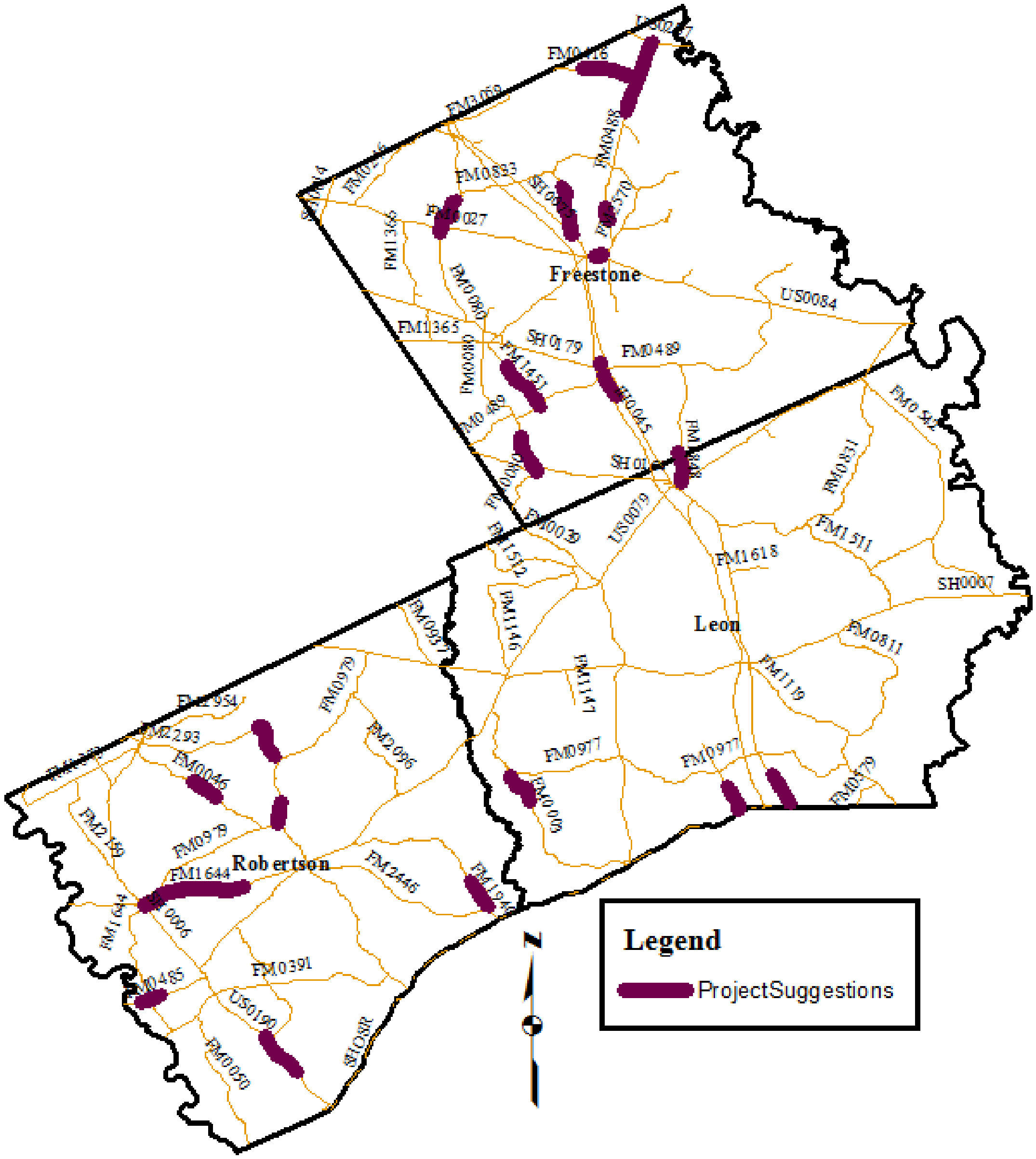


Figure 4.13. Map of Projects Suggested by the AHP Method

While Table 4.11 clearly shows the agreement between the new method based on the AHP and actual district decisions, a map to further illustrate the agreement might be helpful. Figure 4.14 is a map of the Category 1 expenditures within the three counties included in the study. A comparison between Figure 4.13 and Figure 4.14 is provided in Figure 4.15.

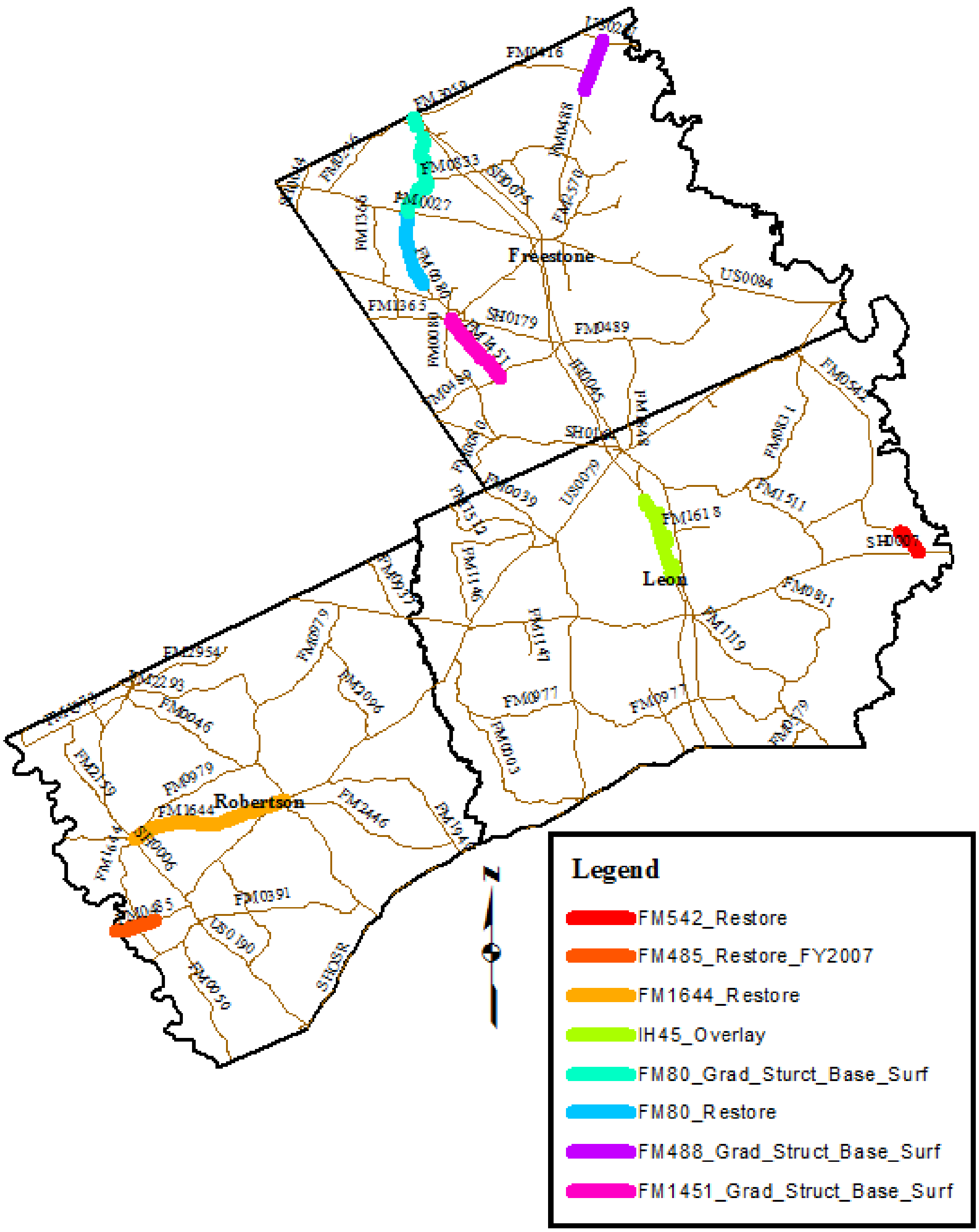


Figure 4.14. Category 1 Projects Map

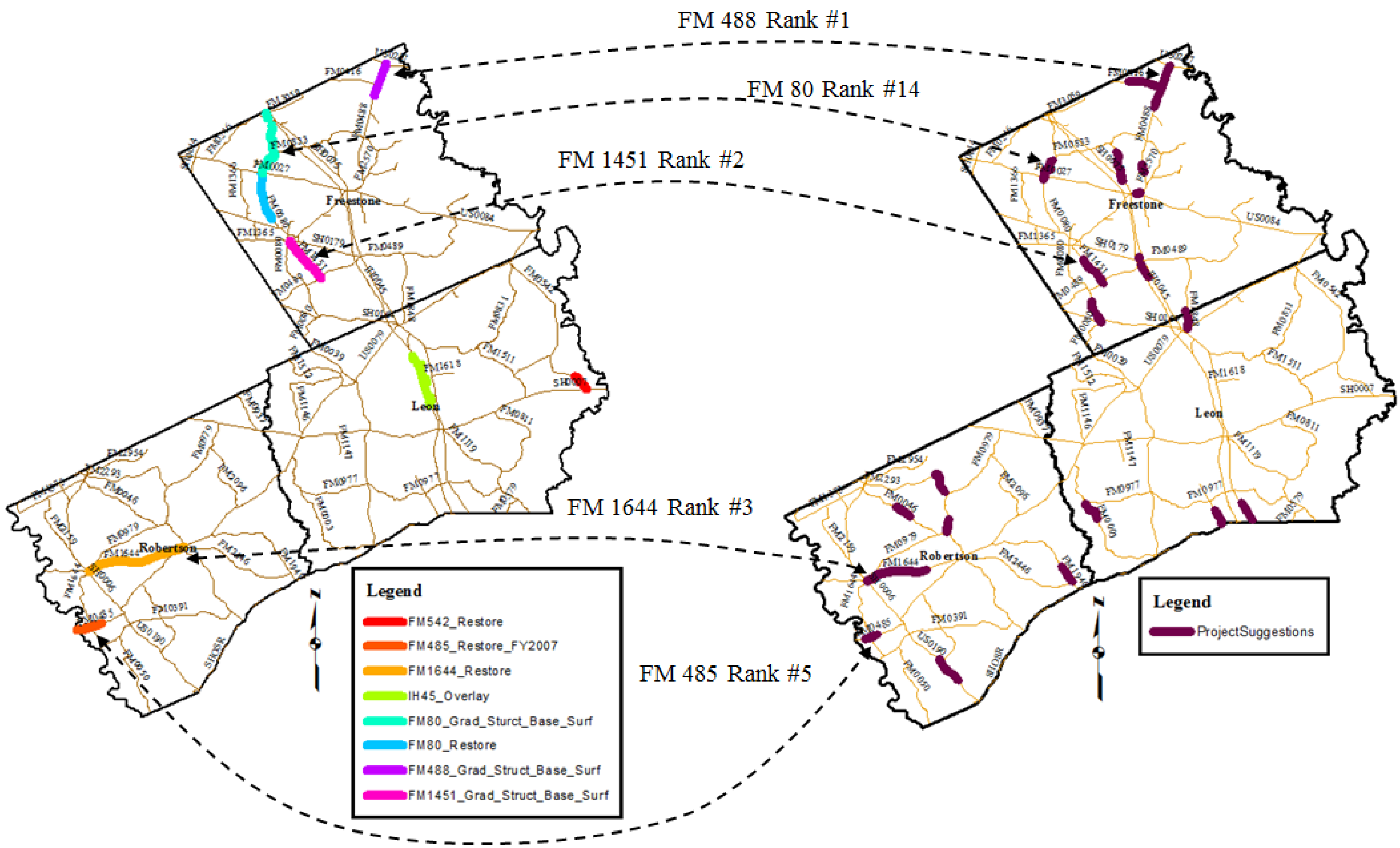


Figure 4.15. Comparison of Category 1 Construction Projects and Projects Selected by New Method

Figure 4.15 indicates the agreement between the new method and projects funded with Category 1 monies. There is particularly good agreement between Category 1 expenditures and projects with a high ranking in the new method. Of the eight Category 1 funds mapped, the new method prioritizes five of the same projects. It is important to note that this is only a comparison between Category 1 construction. The reason for this is that a map of Category 1 construction, routine maintenance contracts, and routine maintenance would be essentially identical to the map of prioritized projects selected in the new method. This fact is based on the agreement expressed in Table 4.11.

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 SUMMARY

The research described in this thesis evaluates and improves the agreement between need estimates performed at network-level pavement management and actual pavement preservation and improvement projects. Specifically, the research assesses the agreement between pavement maintenance and rehabilitation actions recommended by PMIS's needs estimate tool (decision support arm of PMIS) and actual pavement preservation and improvement projects performed by TxDOT's districts. Consequently, an improved decision support method for project selection that accounts for both quantitative and qualitative variables considered by pavement managers and district decision makers was used. This new method is based on the Analytic Hierarchy Process (AHP) and uses data that already exists in PMIS along with inputs from the decision makers.

To determine how TxDOT decision makers felt about PMIS as a project selection and prioritization tool, interviews were conducted with Bryan, Beaumont, Dallas, and Tyler district decision makers. It was found that PMIS's Needs Estimate is not commonly used to select and prioritize projects. Comparisons of actual pavement maintenance and improvement projects from Bryan, Beaumont, and Dallas districts to pavement maintenance and improvement actions recommended by PMIS Needs Estimate tool were performed. These comparisons showed major discrepancies in terms of percent of pavement sections that do not need improvement.

The researcher used the analytic hierarchy process (AHP) as a multi-criteria decision making method as the foundation for a new process for pavement managers. The AHP was used in an attempt to select and prioritize projects that mimicked how decision makers currently operate. Multiple parameters were included and weighted in the process. These parameters included visual distress, current ADT, current truck ADT, condition score, ride quality, and maintenance costs. The visual distress parameter was created by applying the AHP to determine how different distresses should be weighted in the decision making process, The distresses considered in this process were Failures, Alligator Cracking, Longitudinal Cracking, Block Cracking, Deep Rutting, Transverse Cracking, and Patching. Using data from three counties within the Bryan district, it was discovered that the AHP method closely matched preservation decisions currently being made by the districts. Lastly the method was able to take the information regarding each section and combine it in such a way to create realistic preservation projects.

5.2 CONCLUSIONS

Based on the research described here, the following conclusions can be made:

- The agreement between PMIS's Needs Estimate and actual projects was measured by the percent of pavement sections within actual projects that are identified as "Needs Nothing" (%NN). Thus, a perfect agreement will result in zero %NN within the actual projects.
- On average, the percent of "need nothing" pavement sections within Bryan district, for all projects, 1-year prior to construction was 45

percent. For the 10 projects analyzed further, the average percent of NN sections 1, 3, and 5 years prior to actual project construction year was 33, 31, and 42 percent, respectively.

- On average, the percent of "Needs Nothing" pavement sections within Beaumont district, for all projects, 1-year prior to construction was 63 percent. For the 12 projects analyzed further, the average percent of NN sections 1, 3, and 5 years prior to actual project construction year was 76, 68, and 63 percent, respectively.
- On average, the percent of "Needs Nothing" pavement sections within Dallas district, for all projects, 1-year prior to construction was 45 percent. For the 12 projects analyzed further, the average percent of NN sections 1, 3, and 5 years prior to actual project construction year was 59, 66, and 61 percent, respectively.
- There is little agreement between the output of PMIS's Needs Estimate tool and actual construction projects. Primary reasons for this disagreement include the inability of PMIS's Needs Estimates to consider the decision makers preferences and priorities, and also its inability to consider multiple years of condition data simultaneously.
- Through the use of the AHP, the research was able to capture the effect several variables have on the decision making process for the Bryan district. Using this method, preservation project suggestions were created

that more closely matched actual projects than what the current Needs Estimate tool suggests.

- Using actual construction projects from three counties in the Bryan district, the new project selection method matched at least 75 percent of district decisions regarding pavement preservation and improvement projects.
- The method actively seeks to capture decision maker's views and therefore can be tailor made to meet the needs of various districts. Each district faces its own issues and evaluates levels of importance differently, therefore the decision makers must convene and complete the matrices used within the method to meet the regional needs of its travelers.

5.3 RECOMMENDATIONS

The developed method for project selection and prioritization was applied to one district and input was obtained from one decision maker. It is recommended that the developed method be tested and applied at other TxDOT districts before it can be used at the statewide level. It is important for TxDOT to understand that if a system is desired that helps justify and defend preservation decisions, pavement managers and district decision makers must be consulted and their input must be included in the process. The AHP provides an effective platform for this need.

While the method created in the research focuses on information currently available and the assumption that TxDOT preserves the system at a level that implies preservations decisions are appropriate, the method can be customized to include other decision variables. For example, the method can be customized to include pavement long-term performance when distress information and importance based on pavement prediction models become available. Further expansion of the method can include life-cycle costs and other variables that will help move beyond the worst-first process and into long-term planning processes. Current decisions revolve around the needs of specific constituencies located within the TxDOT districts; therefore it might be beneficial to further research the possibility of including public input as a decision parameter. To include this parameter additional research is needed to determine appropriate data collection methods. It would also be important to test this parameter to see if it is already included in the model through correlation with existing decision parameters. These recommendations are mentioned primarily to provide additional research ideas and illustrate that the method is flexible enough to easily incorporate new decision variables or data changes.

Regardless of whether or not the decision method created in the research is expanded, it is important to understand that routine maintenance must be accounted for and that more than the previous year's data should be used when estimating pavement preservation and improvement needs. Also, to make PMIS more effective as a project selection tool, a method to account for sections that are under construction should be established. PMIS should remain uniform from year-to-year and place holders should be included for sections that are under construction and cannot be rated so that gaps do not exist in the data. It should be mentioned that if these placeholders were included, the decision method created in the research could be modified to use post construction data only.

Accountability pressures on TxDOT require rational and justifiable use of pavement preservation and improvement funds. The developed AHP method can help make project selection process at TxDOT more systematic and justifiable, and at the same time representative of the District's realities. Finally, it is recommended that the developed project selection method be computerized and eventually integrated with PMIS.

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APPENDIX A

DETAILED DISCUSSION OF DISTRICT SEAL COAT PROGRAMS

Bryan: The District Pavement and Materials Engineer is responsible for the district wide seal coat program. This engineer uses the seal coat project plans from the previous ten (10) years as a starting point. The limits from these seal coat projects essentially created management sections for the district to look at and the district uses a special query in MapZapper that would average the scores in PMIS for these old seal coat projects. The District likes to look at the weighted average of the scores across the length of a construction project. Turnkey costs could then be used to determine construction cost needs. Projects could be prioritized based on the worst average PMIS condition score for the old seal coat projects. Obviously if these scores indicated a significant distress, a seal coat would not be applied; rather a heavier M&R action would be pursued. Therefore, this methodology helps the district set the seal coat project, but also provides an origin for other M&R projects. The district had also managed to create a seal coat plan that placed the district's roadways on a 7-year seal coat cycle, but funding and the possible move to a tiered approach could lead to modifications in the cycle. TxDOT district forces complete a significant amount of work in preparation for the district wide seal coat project. The majority of this work is base repair. The district uses a rule of thumb that if the roadway needs two weeks or less of in-house work, it can be prepared by TxDOT forces for seal coat, however if the anticipated work would take longer than two weeks, it is likely that this project requires additional construction beyond in-house preparation and a seal coat.

<u>Beaumont:</u> The size of the seal coat program is currently being increased. Location of roadways for the seal coat project typically comes from maintenance supervisors and area engineers (AEs). It is believed that these individuals have the most intimate knowledge of the roadways and provide the best insight on what should be sealed. In-house maintenance forces are being used to prepare roads for the seal coat project, particularly to perform base repair. This type of work has increased as the seal coat program has increased. PMIS is only used as a check, to ensure that poor roadways are receiving treatment; it is not used in initial project selection.

<u>Tyler:</u> Seal coat is popular in Tyler and it is believed that it is the best way to stretch dollars over lane miles. When it comes to spending Category 1 funds, the dollars for the district wide seal coat are pulled off of the top before evaluating any other projects. The initial lists of roadways that need to be sealed are provided to the Director of Operations (DOO) from the maintenance section supervisors. This list is taken and vetted against the dollar amount available for the district wide seal coat project. The roadways and quantity that can be sealed are set based on the dollars available, meaning that some roadways on the list do not receive treatment. For roadways that are selected, in-house maintenance forces play a significant role in preparing the roadway for seal coat. Most of this work is base repair. The seal coat program is further constrained by the amount that the district staff believes the contractor can complete within the seal coat season and how much base repair the maintenance sections can before in front of the seal coat contractor. This information is historical and experienced based. In the past, this has been 250 centerline miles which was believed the maximum amount the contractor could

complete. The district evaluated moving to a cyclical program, but a formal cycle program dissolved due to the fact that enough miles could not be sealed every year to establish the cycle. It also dissolved because experience from the staff has shown that some roadways will require a new seal before its slot in the cycle and some will not require a seal at its designated time.

Dallas: As with the previous three districts, seal coat is extremely important to the Dallas District. So important that the district spent it entire Category 1 PM allocation on the district wide seal coat project. According to the FY 2010 UTP, the Dallas Category 1 PM allocation is approximately $11.25 million. In the past, the Dallas District seal coat project has been between $14 and $15 million. Obviously the reduced amount this year limited the number of roadways that could be sealed. Historically, the seal coat program has been on a 6-year cycle, but many times high volume roadways were not lasting 6 years. The Dallas district also expressed concern over the inability to spend federal dollars on functional class 6 and 7 roadways. This issue had been raised from other districts, but Dallas expressed the need to reclassify some of its lower volume FM roads from class 6 or 7 to functional class 5 so that federal dollars could be used. In the past, district wide seal coat programs were 100% state funded, but now they contain federal dollars, meaning that some roadways that need sealed can no longer be sealed under the district wide seal coat program. District maintenance forces are used to prepare roads for seal coat. This in-house work is generally focused on base repairs. PMIS is not directly used when selecting roadways, but the district staff is aware that the

DE will look at MapZapper to ensure that all roadways with a CS below 70 are being addressed.

APPENDIX B

DETAILED TXDOT INTERVIEW RESPONSES

BEAUMONT DISTRICT QUESTIONNAIRE – July 9, 2010

1. **Please describe how the District currently selects roadways for a construction project using Category 1 money (pavement preservation and rehabilitation).**

   Response: There has been personnel turnover in the Beaumont District that was evident during questions. It was obvious that the District was still in somewhat of a transition from the way the old regime made decisions and the way the new District management wants to do things. This question received two responses, one regarding how they typically make decisions with Category 1 funding and one regarding how they made decisions with ARRA funds. From an ARRA standpoint, PMIS weighed heavily on which roads would receive work. The quick turn-around required with ARRA funds led to the District evaluating PMIS and placing roads with a condition score below 70 at the top of the list. The goal here was essentially to improve as many lane miles as possible ("lipstick on a pig"). Decision making with regards to more traditional funding, specifically category 1, relies much less on PMIS. In the past, for project selection, the District office puts out a call for projects to its area offices. At this level, the AEs and the maintenance supervisors have the ability to identify the poor roads needing work in their area. This is the initial selection process and is coupled with the District management's knowledge of poor roads in the District. Recently, under the new District leadership, a flip chart 2-D matrix was created to help prioritize project selection. This matrix included variables such as ADT, cost of project, public perception, previous commitments. This was done with staff level input. PMIS maps were used to compare if project selection was matching poor scores, put PMIS did not play an initial role or a role in finalizing what projects would be let. The staff level input narrows the list and then the roads are generally ridden (ideally) to make the final project decision. The District is aware of the possible move to the tiered approach and also that PMIS currently serves as the pavement "report card."

2. **Please describe how the District currently selects the type of treatment (or work action) that is applied to the projects identified from question 1.**

   Response: The short list generated above is used to begin this evaluation. Additional field testing is often performed on candidate projects. This field testing is typically coring and FWD. Because funding is such a major consideration, the type of M&R action is often based on the $/mile for a project. The District tries to stretch its dollars as far as possible while treating the road properly. ADT also plays a large role in treatment selection. First because of its design impact, but also on traffic control. This is similar to the Bryan District where the Districts are trying to determine how high of an ADT can run on raw base. Essentially, when a restore or rehab project is required, one of the main questions is whether or not the job can be done without detour pavement. From a cost perspective, the District is trying to push the envelope on ADT that runs on raw base. The Needs Estimate tool in PMIS is NOT used.

3. **Does the District have a formal definition of the following work actions? If yes, what is that definition?**

   Response: The District does not have a formal definition of PM, LRhb, MRhb, and HRhb as it appears in the PMIS Needs Estimate tool. In fact, the District does not use the PMIS Needs Estimate. From an M&R classification standpoint, design requirements of 2R, 3R, and 4R are the distinctions between levels of rehabilitation.

4. **If the answer to the question above is yes, does the District have a $/mi defined for each type of work action?**

   Response: Project $/mi is a big deal to Beaumont. Because of the 4-year plan required by administration, Beaumont likes to have a $/mi so that projects can be set in advance. This allows the District to establish multiple projects for several years in the future based on $/mi. The comment was made several times that these $/mi numbers were used to "stretch" their dollars.

5. **How is routine maintenance money competed for between the different maintenance sections within the District?**

   Response: Under the old District administration, maintenance sections did not manage their own budget; it was managed from the District office. Last year, the DOM gave all sections a budget. The DOM (Jack Moser) was unavailable for the meeting, but the DE (Randy Redmond) indicated that he believes the budgets were determined based on lane miles, VMT, and budget history.

6. **Does your District use in-house (routine maintenance) forces to prepare roadways for construction projects? If yes, how?**

Response: The current District administration is enlarging the annual seal coat contract. The current District administration is a proponent of seal coat as a PM measure and has increased the $ amount for its annual letting. With this new philosophy, in-house forces are being used to prepare roads for the District wide seal coat. This includes base repair. In the past, routine maintenance contracts have been let to help get roads ready for District wide seal, but with the current District leadership, it is more of an in-house issue.

7. **How, if at all, does the District use PMIS when determining which roadways need pavement work?**

   Response: It is used mainly as a check and has little to no weight on initial decision making. The Needs Estimate tool is not used at all.

8. **How, if at all, does the District use PMIS when selecting a type of work to be performed on a section of roadway?**

   Response: Essentially the same answer as above. Visual (site visit) data is used both in project selection and M&R action, but this information is not pulled from PMIS.

9. **How confident are you in PMIS's optimization tool?**

   Response: Is not used within the District.

BRYAN DISTIRCT QUESTIONNAIRE – JUNE 18, 2010

1. **Please describe how the District currently selects roadways for a construction project using Category 1 money (pavement preservation and rehabilitation).**

   Response: The Bryan District is currently modifying the way in which it selects projects for Category 1 funds. In the past, the District Materials and Pavement

Engineer has used seal coat plans from the last 10 years as a starting point. This information would be placed in MapZapper with the year the seal was placed and different colors were mapped to display when the seal coat was placed. The limits from these seal coat projects essentially created management sections for the District to look at and the District had Craig Cox write a special query in MapZapper that would average the scores in PMIS for these old seal coat projects. The District likes to look at the weighted average of the scores across the length of a construction project. Turnkey costs could then be used to determine construction cost needs. Projects could be prioritized based on the worst average PMIS condition score for the old seal coat projects. When it comes to pavement preservation in the Bryan District, ride does not factor into the thinking very much. It is agreed among the District decision makers that due to the expansive nature of the soils in the Bryan District that ride could be poor, but the actual condition of the pavement could be good. The new method used is based partly on the knowledge that the Department could be moving to the tiered system of pavement scoring. Roadways within the District are broken out based on ADT. If the ADT < 2500, it is thought that the project can be done under traffic, even if that means running the traffic on raw base during construction. The next benchmark is < 7000 because at that point, you might be able to perform the construction under traffic. Anything with ADT > 7000 requires detours and/or detour pavement to perform the construction. In summary, one of the major factors when prioritizing roadways is how traffic can and will be handled during construction. A map is then generated showing the amount of patching, failures, and ADT. The reason patching and failures are mapped is because the District believes the number of failures and patching on a roadway indicate if the roadway requires more significant work such as a rehab. Also, patching is important because if there are significant RM patches that have held the road together, maybe a seal coat is needed to preserve the integrity of the patches. The District used to be on a 7 year seal coat cycle, but with the new scheme, look at years since last treatment may fall further down the ladder. The District Materials and Pavement Engineer is essentially the keeper of the information and developer of the prioritization scheme. This engineer is solely responsible for the District Wide seal coat program and is the beginning point for the rehab program. Roadways requiring rehabilitation are typically driven by District staff, AEs have little involvement in the selection of projects. AEs are provided the preliminary project list by the District Material and Pavement Engineer and are given the opportunity to provide input on any other needs, but their primary purpose is providing input on project limits.

2. **Please describe how the District currently selects the type of treatment (or work action) that is applied to the projects identified from question 1.**

   Response: The PMIS condition score is broken out into the various distresses, 1 failure in a ½ mile section will not push the score below 70, but 2 will, and therefore the number of failures are plotted on maps. If more than 25% of the area requires spot repair, the District usually looks at going to rehab. To determine this, the cost effectiveness scarify and reshape (and maybe add base) is compared to extensive base repair prior to a seal. Those that are in the worst condition are ridden by District staff and then prioritized by them. Anything above a seal coat is ridden by District staff and has further field testing performed.

3. **Does the District have a formal definition of the following work actions? If yes, what is that definition?**

   Response: The District does not have a formal definition of PM, LRhb, MRhb, and HRhb as it appears in the PMIS Needs Estimate tool. In fact, the District does not use the PMIS Needs Estimate. When defining PM and Rehab., the District bases the work on an email sent by Bob Richardson, the Bryan District Design Engineer, with input from the Design Division.

4. **If the answer to the question above is yes, does the District have a $/mi defined for each type of work action?**

   Response: Bryan likes to use turnkey prices by dividing historical construction project prices by length or area to get a $/unit.

5. **How is routine maintenance money competed for between the different maintenance sections within the District?**

   Response: Need to ask Bryan DOO, Terry Paholek.

6. **Does your District use in-house (routine maintenance) forces to prepare roadways for construction projects? If yes, how?**

   Response: District forces do a significant amount of in-house work to prepare for construction projects, mainly repairs in preparation for seal coat. The District has a rule of thumb, that if in-house forces can complete the work in 2-weeks, then it should be done to prepare for construction, however if the amount of work required on the roadway would take longer than 2-weeks, maybe the job is too big for in-house maintenance.

7. **How, if at all, does the District use PMIS when determining which roadways need pavement work?**

   Response: The condition score generated by PMIS is broken out into the individual distresses that make up the score. Failures and patches are specifically targeted because they are indications of possible structural issues within the pavement.

8. **How, if at all, does the District use PMIS when selecting a type of work to be performed on a section of roadway?**

   Response: Essentially, this is the same answer as above, but it can be pointed out that as the number of failures and patches goes up, the District begins to look more closely at rehabilitation rather than preventative maintenance.

9. **How confident are you in PMIS's optimization tool?**

   Response: Is not used within the District.

<u>DALLAS DISTRICT QUESTIONNAIRE – July 27, 2010</u>

1. **Please describe how the District currently selects roadways for a construction project using Category 1 money (pavement preservation and rehabilitation).**

   Response: The District prefers to use a formula driven approach when distributing money for projects. The formula is based on the original rehab formula from the UTP and PMIS information. This approach has been used for spending both category 1 funds and district maintenance funds. The District expressed issues with this method as funds become more limited, only one or two projects can be chosen and then all of the money is gone. During the last FY, the district spent its entire Cat 1 PM allocation on the seal coat program. This program was not as large as it had been in the past. Historically, the seal coat program was approximately $15 million, but that was cut this year to approximately $12 million. Historically, the seal coat program has operated on a 6-year cycle, but many times the high volume roadways are not lasting 6 years. Also, with current budget constraints and the inability to spend federal dollars on functional classification 6 or 7 means some roads that were scheduled for seal coats will not receive them at the anticipated cycle time. The district is currently trying to have some of their functional class 6 and 7 roads reclassified to class 5 so that federal dollars can be used on these roadways. With the large amount of concrete paving in the district, the district tries to let an area wide concrete repair project yearly. The District also looks at projects the AEs want done in their area.

2. **Please describe how the District currently selects the type of treatment (or work action) that is applied to the projects identified from question 1.**

   Response: When selecting treatment types, the seal coat program has operated on a cycle, while other, more extensive M&R projects are based initially on knowledge of distress on the roadway. This knowledge is typically acquired through site visits and riding the roads. The District express that this was the best way to know what was occurring. FWD data is used to determine the extent of what needs to be done and if it will be a good investment. The District is not opposed to collecting network level

FWD, but indicated that another piece of equipment would be required to collect that much data.

3. **Does the District have a formal definition of the following work actions? If yes, what is that definition?**

   Response: The District does not have a formal definition of PM, LRhb, MRhb, or HRhb. These definitions are typically driven by how and where the money needs to be spent. Essentially, it will be called whatever it needs to be called to get the work done.

4. **If the answer to the question above is yes, does the District have a $/mi defined for each type of work action?**

   Response: There is no formal definition, but the District is concerned with budget. Based on history, the budget for seal coat projects is often known but with limited funding the seal coat program cannot be as large as it has been in the past. To maintain the historical seal coat cycle, the district needs approximately $14 million/year, but in FY 2010, Dallas got just over $11 million. Essentially, the district tries to push projects through that are need and they can be classified as whatever works the best. Definitions in no way line-up with PMIS.

5. **How is routine maintenance money competed for between the different maintenance sections within the District?**

   Response: Strategy 105 and 144 monies are allocated based on formulas. The formula used is based on the old UTP rehab formula and PMIS. There was a time when category 1 money could be transferred to strategy 144 (maintenance budget) so in-house forces could concentrate on failures or other issues that could be solved with TxDOT personnel. Unfortunately, this can no longer be done without going to the legislative budget board and having the governor sign-off. Dallas does like to use in-house forces when possible because it allows certain project to be achieved without going through all of the design development. For example, adding 6' to the end of culverts without running hydraulics.

6. **Does your District use in-house (routine maintenance) forces to prepare roadways for construction projects? If yes, how?**

   Response: Maintenance sections are used to prepare roads for seal coat. This is mainly base repair work. Staff indicated that some sections are better than others at roadway preparation.

7. **How, if at all, does the District use PMIS when determining which roadways need pavement work?**

   Response: The district views PMIS more as an inventory system rather than a maintenance tool. Work being performed is checked against the condition score in PMIS because it is the statewide scorecard. Try to make sure the projects are taking care of what is red, but the District appears confident that they know what and where the problems are and projects are created to deal with these problems. The DE did not meet with us, but they are aware that the DE will look at MapZapper to ensure the areas in red are being addressed.

8. **How, if at all, does the District use PMIS when selecting a type of work to be performed on a section of roadway?**

Response: No, the District does not use PMIS when determining what M&R action to perform. It does not consider the Needs Estimate recommendations. The district views PMIS as a snapshot in time and feels that it needs to take the next step to be used as a prediction and decision support tool. If the needs estimate is used at all, it is viewed as an order of magnitude gauge, but it does not change the decision. The CS is looked at the most because it is the report card.

9. **How confident are you in PMIS's optimization tool?**

Response: Is not used within the District.

<u>TYLER DISTRICT QUESTIONNAIRE – July 16, 2010</u>

1. **Please describe how the District currently selects roadways for a construction project using Category 1 money (pavement preservation and rehabilitation).**

Response: The District staff first evaluates the roadways that require seal coat. This initial list of roadways requiring seal coat comes from the maintenance section supervisors. The Director of Operations asks the section supervisors for a list of roadways that require seal coat. With this list and the known dollar amount for the District wide seal coat, the number (and length) of roadways that are sealed is set based on the dollar amount of the project. This is driven also by the 4 year pavement management plan. With the knowledge of which roadways will be sealed, the staff turns its attention to creating a list to spend the remainder of category 1 funds. The staff attempted to create a preliminary list by asking the maintenance section supervisors to provide a list of needs within their section (a top 5 list or sorts), but unfortunately this generated little response. Therefore the District staff created a project list based primarily on first-hand visual knowledge of roadways with problems. This list was compared with PMIS maps in a staff meeting to ensure that anything that was red on the maps was going to be included in a construction project or was being handled with routine maintenance. The District Engineer was insistent that anything below 70 receive some sort of treatment to correct the issue. In terms of ranking, the priority decisions were made primarily on the DOC and DOO's knowledge of the roadways and distresses. There is an understanding that PMIS is the "report card" but concerns were raised with it being part of the DE's annual performance evaluation. Concern was expressed on the "time lag" between the PMIS evaluation and when the scores are available. The District has a firm belief that major trouble areas are often corrected between the PMIS visual evaluation and the availability of scores. This again speaks to TxDOT's ability to maintain the system at a relatively high level with "in-house" forces.

2. **Please describe how the District currently selects the type of treatment (or work action) that is applied to the projects identified from question 1.**

   Response: When selecting M&R actions, the District's decisions are distress driven. Knowledge of these distresses is generally gleaned from visual evaluations or rides made by the DOC. With knowledge of the distresses, the DOC can decide what additional field testing will occur. It is not uncommon for the District to obtain cores and FWD data when deciding which M&R action to perform. GPR has been obtained in extreme cases. To further evaluate what should occur, the District staff, but particularly the DOC, will look at routine maintenance on the section. The type of maintenance activity and its success will be evaluated to determine the extent of the M&R activity. Lastly, the type of section (rural, curb&gutter, city but no C&G, etc) and where it is located play a role in what M&R action will be performed. The District also mentioned that one of the major driving factors is funding. The DoTP&D commented that when funding is limited, treatments must be made to keep the roadway together when in reality a "heavier" treatment would have been preferred. I asked if they felt network level FWD would be beneficial and the DOC commented that he did not think so. His comment was why would you gather data if it is not needed in the near term. The thought seemed to be that when you reached a point of determining what action to perform, that FWD could be performed then, but before that it would not provide substantially useful information.

3. **Does the District have a formal definition of the following work actions? If yes, what is that definition?**

   Response: The District does not have a formal definition of PM, LRhb, MRhb, or HRhb. They are currently referring to a memo from John Barton on some of these definitions. I am trying to obtain a copy of that memo. The memo does state that any hot-mix overlay project less than 2" falls into the PM category.

4. **If the answer to the question above is yes, does the District have a $/mi defined for each type of work action?**

   Response: There is no formal definition, but the District is concerned with budget. Based on history, the budget for seal coat projects is often known and can be assigned. At one time, the District selected 250 miles worth of seal coat for the

District wide seal coat project because that is how many miles they felt the contractor could complete within the seal coat season. The DE would like to make the seal coat project much more needs based by deciding how many SY of seal coat need to be performed that year. The DOO indicated that they had tried this before, specifically when they tried to establish a seal coat "cycle" within the District. This cycle process quickly dissolved because enough miles could not be seal in one year to create the cycle process, but also because it became apparent that some roads would require sealing before their turn in the cycle and others would not need to be sealed when their turn came back around. While there is no $/mi approach for other projects, the staff is obviously concerned with stretching dollars to the pavement.

5. **How is routine maintenance money competed for between the different maintenance sections within the District?**

   Response: The DE wants to move to a needs based approach. The DE wants the District to evolve to a point where the needs of the District are evaluated and that is how maintenance budgets are determined. The challenge is that maintenance supervisors are not keen on the idea of giving up money for their sections and generally just look out for their sections. Currently the maintenance sections budgets are based on historical budgets. The maintenance section supervisors are currently responsible for their material budgets, but the DE wants them to be responsible for their entire budget, especially when they reach the needs based method.

6. **Does your District use in-house (routine maintenance) forces to prepare roadways for construction projects? If yes, how?**

Response: Maintenance sections play an integral role in preparing roadways for seal coat. Sections are responsible for preparing the roadways for District wide seal, including base repair. The amount of roadway the sections can prepare has often limited the size and extent of the District wide seal coat project. I asked if there was any thought to letting a base repair contract to help get roads ready and I was told that it had been done a long time ago and TxDOT Administration made the comment that base repairs should be done in-house rather than with a contract. The staff commented that with the current funding situation that administration might not be as opposed to a base repair contract if it meant increasing the seal coat project and provided PM work on more mileage.

7. **How, if at all, does the District use PMIS when determining which roadways need pavement work?**

   Response: It is mainly used as a check to ensure construction decisions correspond with the overall condition score. The maps are used to make sure everything in red is being addressed either through contract or in-house. The Needs Estimate tool is not used at all. However, DE did express interest in evaluating the Tyler construction data to determine if it was following the Needs Estimate tool. He was particularly intrigued by the notion of following the Needs Estimate and scores through history to determine if it justified the construction project. This interest came after a discussion of construction projects for the Beaumont District.

8. **How, if at all, does the District use PMIS when selecting a type of work to be performed on a section of roadway?**

Response: Essentially the same answer as above. Visual (site visit) data is used both in project selection and M&R action, but this information is not pulled from PMIS.

9. **How confident are you in PMIS's optimization tool?**

   Response: Is not used within the District.

APPENDIX C

INITIAL DECISION PARAMETER SURVEY AND SUMMARY

Table C-1. Blank Parameter Survey

	Weight Given to Parameter						
Input Parameters	**NA**	**None**	**Very Low**	**Low**	**Medium**	**High**	**Very High**
Current ADT							
Current Truck ADT							
Future ADT							
Future Truck ADT							
PMIS Condition Score							
PMIS Distress Score							
Ride Quality (From PMIS or other)							
Rutting							
Visual Distress (Site Visit)							
Public input/involvement							
TxDOT Admin. input/involvement							
Political input/involvement							
Sections that receive the most RM[1]							
Effectiveness of RM[1] actions							
Structural Strength Index (SSI)							
Additional Field Testing							
Pavement Prediction Models							
Economic Development							
Condition of Adjacent Sections							
Evacuation Route							
Population Density							
Projected 18-kip Equivalent							
Date Since Last M&R Action							
Functional Classification							
PMIS Individual Distresses							
Other:							
Other:							
Other:							
Other:							
Other:							

[1] RM = Routine Maintenance

Table C-2. Summarized Parameter Survey (Decision: Which Roadways Receive Work?)

Rank	Input Parameters	Weighted Avg.	Highest Ranking	Lowest Ranking	Most Frequent Ranking
N/A	Other: Funding	5.00	Very High	N/A	Very High
N/A	Other: Climate	5.00	Very High	N/A	Very High
N/A	Other: Subgrade	5.00	Very High	N/A	Very High
1	Visual Distress (Site Visit)	4.23	Very High	Low	Very High
2	Current ADT	4.15	Very High	Medium	High
3	Current Truck ADT	3.85	Very High	Low	High
4	PMIS Distress Score	3.77	Very High	Low	High
5	Sections that receive the most RM[1]	3.54	Very High	None	Very High/High
6	Projected 18-kip Equivalent	3.50	Very High	Low	High
T7	Future Truck ADT	3.46	Very High	Low	High
T7	PMIS Condition Score	3.46	Very High	Low	High
9	Rutting	3.38	Very High	Low	High/Medium
T10	Future ADT	3.31	Very High	Low	High/Low
T10	PMIS Individual Distresses	3.31	Very High	None	Medium
12	Additional Field Testing	3.08	Very High	None	Medium
13	Effectiveness of RM[1] actions	2.85	Very High	None	Medium
14	TxDOT Admin. input/involvement	2.75	High	None	High
T15	Economic Development	2.69	High	None	Medium
T15	Functional Classification	2.69	Very High	Very Low	Medium/Low
T17	Ride Quality (From PMIS or other)	2.62	High	Low	Low
T17	Public input/involvement	2.62	High	None	Medium
19	Political input/involvement	2.58	High	None	Medium
20	Evacuation Route	2.42	High	Very Low	Medium
T21	Population Density	2.38	High	None	Medium
T21	Date Since Last M&R Action	2.38	High	None	Medium
23	Pavement Prediction Models	2.30	High	Very Low	Medium
24	Condition of Adjacent Sections	2.25	Medium	Very Low	Medium
25	Structural Strength Index (SSI)	2.08	High	Very Low	Very Low

Table C-3. Summarized Parameter Survey (Decision: What Preservation Treatment Should be Applied?)

Rank	Input Parameters	Weighted Avg.	Highest Ranking	Lowest Ranking	Most Frequent Ranking
N/A	Other: Funding	5.00	Very High	N/A	Very High
N/A	Other: FWD	5.00	Very High	N/A	Very High
N/A	Other: FPS-19W	5.00	Very High	N/A	Very High
N/A	Other: Climate	5.00	Very High	N/A	Very High
N/A	Other: Subgrade	5.00	Very High	N/A	Very High
1	Visual Distress (Site Visit)	4.38	Very High	Low	Very High
2	Current Truck ADT	4.31	Very High	Medium	Very High
T3	Current ADT	4.23	Very High	Medium	High
T3	Additional Field Testing	4.23	Very High	Low	Very High
5	Future Truck ADT	4.00	Very High	Medium	High
6	Projected 18-kip Equivalent	3.92	Very High	Low	High
7	Future ADT	3.69	Very High	Low	Medium
8	Rutting	3.54	Very High	Low	High
9	PMIS Distress Score	3.31	Very High	Low	High
10	PMIS Individual Distresses	3.15	Very High	None	High
11	TxDOT Admin. input/involvement	3.08	Very High	None	High
12	PMIS Condition Score	3.08	High	Low	High
T13	Sections that receive the most RM[1]	3.00	Very High	None	High
T13	Effectiveness of RM[1] actions	3.00	High	Low	High
T15	Ride Quality (From PMIS or other)	2.69	High	Low	Low
T15	Economic Development	2.69	High	None	Medium
17	Condition of Adjacent Sections	2.63	High	Very Low	Low
18	Functional Classification	2.55	High	Very Low	Low
19	Pavement Prediction Models	2.46	High	None	Medium
20	Evacuation Route	2.31	High	Very Low	Low
21	Political input/involvement	2.25	High	None	Medium
22	Population Density	2.23	High	None	Medium
23	Structural Strength Index (SSI)	2.08	High	None	Low/Very Low
24	Public input/involvement	2.00	High	None	Low
25	Date Since Last M&R Action	1.92	High	Very Low	Very Low

APPENDIX D

EXAMPLES OF PYTHON AND EXCEL CODE USED IN CALCULATIONS

SelectionMatrix.py - F:\AHP\Roadway Select\Weight Matrices\SelectionMatrix.py

File Edit Format Run Options Windows Help

```
import numpy
SelectionMatrix = numpy.loadtxt('SelectionMatrix.txt',delimiter = '\t')
print SelectionMatrix.shape
print SelectionMatrix
import pylab
[eigenvalue, eigenvector] = pylab.eig(SelectionMatrix)
print eigenvalue
print eigenvector
from numpy import *
savetxt('Selectioneigen.txt', eigenvector, fmt = "%12.6G")
```

Figure D-1. Example Python Code to Calculate Eigenvalue and Eigenvector

=IF($G4=H$3,1,IF($G4-H$3>0,$G4-H$3+1,(1/(ABS($G4-H$3)+1))))

Section	BRM	BRM D	ERM	ERM D	AADT	Null Compare	3300	5800	5800	5000	740	740	740	740	740	740	740	740	740	740
							5	5	5	5	1	1	1	1	1	1	1	1	1	1
BU0084RK	344	0	344	0.5	3300	5	1	1	1	1	5	5	5	5	5	5	5	5	5	5
BU0084RK	344	0.5	344	1	5800	5	1	1	1	1	5	5	5	5	5	5	5	5	5	5
BU0084RK	344	1	346	0	5800	5	1	1	1	1	5	5	5	5	5	5	5	5	5	5
BU0084RK	346	0	346	0.3	5000	5	1	1	1	1	5	5	5	5	5	5	5	5	5	5
FM0003 K	374	0	374	0.5	740	1	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1
FM0003 K	374	0.5	374	1	740	1	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1
FM0003 K	374	1	374	1.5	740	1	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1
FM0003 K	374	1.5	376	0	740	1	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1
FM0003 K	376	0	376	0.5	740	1	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1
FM0003 K	376	0.5	376	1	740	1	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1
FM0003 K	376	1	376	1.5	740	1	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1
FM0003 K	376	1.5	378	0	740	1	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1
FM0003 K	378	0	378	0.5	740	1	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1
FM0003 K	378	0.5	378	1	740	1	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1

=IF(AND(F4>=0,F4<=1000),1,IF(AND(F4>1000,F4<=2000),3,IF(AND(F4>2000,F4<=7000),5,IF(AND(F4>7000,
F4<=10000),7,IF(F4>10000,9,"error")))))

Figure D-2. Example Excel Logic Statements for Section vs. Section Competition

System	Section	BRM	BRM D	ERM	ERM D	Type		Max Patching	Max Failure	Max Block	Max Allig	Max Long	Max Transv.	Max Rut		Distress Number
							Weight	0.1085	0.4488	0.0264	0.1342	0.0452	0.0241	0.2128		
Other	BU0084RK	344	0	344	0.5	8		0.180292	0.256266	0	0.319513	1.243523	0.304707	0.322307		0.309549
Other	BU0084RK	344	0.5	344	1	8		0.180292	0.256266	0	0.319513	0.209817	0.304707	0.322307		0.262859
Other	BU0084RK	344	1	346	0	8		0.180292	0.256266	0	0.319513	1.533903	0.304707	0.322307		0.322664
Other	BU0084RK	346	0	346	0.3	5		0.180292	0.256266	0	0.319513	0.577862	0.304707	0.322307		0.279483
FM	FM0003 K	374	0	374	0.5	5		0.325782	0.492077	0	0.319513	0.209817	0.304707	0.322307		0.384473
FM	FM0003 K	374	0.5	374	1	5		0.325782	0.492077	0	0.319513	0.209817	0.304707	0.322307		0.384473
FM	FM0003 K	374	1	374	1.5	5		0.658496	0.256266	0	0.319513	0.209817	0.304707	0.322307		0.314732
FM	FM0003 K	374	1.5	376	0	5		0.867966	0.778927	0	0.319513	0.209817	0.304707	0.322307		0.572023
FM	FM0003 K	376	0	376	0.5	5		0.325782	0.492077	0	0.319513	0.209817	0.304707	0.322307		0.384473
FM	FM0003 K	376	0.5	376	1	5		0.180292	0.492077	0	0.319513	0.209817	0.304707	0.322307		0.368691
FM	FM0003 K	376	1	376	1.5	5		0.325782	0.492077	0	0.319513	0.209817	0.304707	0.322307		0.384473
FM	FM0003 K	376	1.5	378	0	5		1.423883	2.438927	0	0.319513	0.209817	0.304707	0.322307		1.377333
FM	FM0003 K	378	0	378	0.5	5		0.658496	0.256266	0	0.319513	0.209817	0.304707	0.322307		0.314732
FM	FM0003 K	378	0.5	378	1	5		0.658496	0.256266	0	0.319513	0.209817	0.304707	0.322307		0.314732
FM	FM0003 K	378	1	378	1.5	5		0.180292	0.256266	0	0.319513	0.209817	0.304707	0.632053		0.328777
FM	FM0003 K	378	1.5	378	2	5		0.180292	0.256266	0	0.319513	0.209817	0.304707	0.322307		0.262859
FM	FM0003 K	380	0	380	0.5	5		0.658496	0.778927	0	0.319513	0.209817	0.304707	1.647514		0.831323
FM	FM0003 K	380	0.5	380	1	5		0.180292	0.256266	0	0.319513	0.209817	0.304707	3.142098		0.862947
FM	FM0003 K	380	1	380	1.5	5		0.180292	2.438927	0	0.319513	0.209817	0.304707	2.742257		1.757433
FM	FM0003 K	380	1.5	382	0	5		0.180292	2.844181	0	0.319513	0.209817	0.304707	3.142098		2.024403
FM	FM0003 K	382	0	382	0.5	5		0.180292	0.256266	0	0.319513	0.209817	0.304707	0.322307		0.262859
FM	FM0003 K	382	0.5	382	1	5		0.180292	0.492077	0	0.319513	0.209817	0.304707	0.322307		0.368691
FM	FM0003 K	382	1	382	1.5	5		0.180292	0.492077	0	0.319513	0.209817	0.304707	0.322307		0.368691
FM	FM0003 K	382	1.5	384	0	5		0.180292	0.492077	0	0.319513	0.209817	0.304707	0.632053		0.434609
FM	FM0003 K	384	0	384	0.5	5		0.180292	0.256266	0	0.319513	0.209817	0.304707	0.322307		0.262859

=(I3*I2)+(J3*J2)+(K3*K2)+(L3*L2)+(M3*M2)+(N3*N2)+(O3*O2)

Figure D-3. Example Excel Logic Statement to Aggregate Distresses into Distress Number

VITA

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