Strategies to Improve and Preserve Flexible Pavement at Intersections

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16. Abstract
Many rural intersections originally constructed with thin untreated flexible base and hot mix or a two-course surface treatment experience severe pushing, shoving and rutting. These failures cause an extremely rough surface that can cause damage to small vehicles and potentially cause motorists to lose control of their vehicle. These distresses almost always result in complete failure of the existing pavement that must be repaired several times during the life of the roadway by maintenance forces. Pavement sections constructed with the same materials adjacent to the intersection perform adequately until the approach (approximately 150 ft in advance) of the intersection and in the intersection itself when the failures become apparent.

The mechanisms of intersection pavement failures and the best practices to minimize the failures at existing intersection pavements are discussed in this report. The outcome of this project is an expert system that can be used to reduce the frequency of maintenance needed at rural intersections with consideration of the life-cycle cost analysis.

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Strategies to Improve and Preserve Flexible Pavement at Intersections

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Abstract

Many rural intersections originally constructed with thin untreated flexible base and hot mix or a two-course surface treatment experience severe pushing, shoving and rutting. These failures cause an extremely rough surface that can cause damage to small vehicles and potentially cause motorists to lose control of their vehicle. These distresses almost always result in complete failure of the existing pavement that must be repaired several times during the life of the roadway by maintenance forces. Pavement sections constructed with the same materials adjacent to the intersection perform adequately until the approach (approximately 150 ft in advance) of the intersection and in the intersection itself when the failures become apparent.

The mechanisms of intersection pavement failures and the best practices to minimize the failures at existing intersection pavements are discussed in this report. The outcome of this project is an expert system that can be used to reduce the frequency of maintenance needed at rural intersections with consideration of the life-cycle cost analysis.

Implementation Statement

An expert system has been developed to provide an online tool that will assist engineers to determine remediation strategies to improve and preserve flexible pavement at intersections.

At this time, the recommendations should be to develop training courses for TXDOT staff on the products from this research project (expert system and guidelines). In addition, few districts should utilize the products for evaluation as part of a pilot implementation project on a number of new projects to confirm the usefulness and benefits of these tools. As part of the implementation, a refinement of the guidelines should be undertaken with assistance from the TxDOT staff.

TABLE OF CONTENTS

List of Figures

List of Tables

CHAPTER 1 - INTRODUCTION

STATE OF PROBLEM

Rural intersections originally constructed with thin untreated flexible base and hot mix or a two-course surface treatment tend to experience severe pushing, shoving and rutting. These failures cause an extremely rough surface that can cause damage to small vehicles and potentially cause motorists to lose control of their vehicles. These distresses almost always result in complete failure of the existing pavement that must be repaired several times during the life of the roadway by maintenance forces. In most cases, pavements constructed with the same materials and cross-sections adjacent to the intersection perform adequately.

The sources of and solutions for failure of the intersections in urban areas are well researched and a number of solutions (such as full-depth concrete slabs, white topping, high quality hot mix asphalt) have been implemented. For example, the National Asphalt Pavement Association (NAPA) and the American Concrete Pavement Association (ACPA) have several documents and training materials available for this purpose. Little attention has been focused toward the rural low-volume road intersections in the US. A vast body of knowledge is available from work done in other countries (e.g., Africa, Southeast Asia, Australia and New Zealand) where the majority of their highway networks are either unpaved or are covered with thin surface treatment. The primary motivation for reconstruction or rehabilitation of the urban high-volume intersections is the speed of the operation to minimize the road closure, and the economy of the solution is of the secondary consideration. However, to develop implementable solutions for the rural intersections, the economy of the solution plays a primary role.

The goal of this project is to understand the mechanisms of intersection pavement failures and to determine the best practices to minimize the failures at existing intersections. The outcome of this project should help to reduce the frequency of maintenance needed at rural intersections. This project would also determine how the mechanisms causing the failures at intersections can be mitigated through design and construction modifications. The outcome will also be used to provide solutions that can be readily and economically carried out considering the location of the project, the construction practices, and the type of potential or actual damage at the intersections.

OBJECTIVES

The basic objective of this project is to accumulate the background information necessary to develop a guide as a decision tool for pavement and maintenance engineers involved in the design, maintenance and rehabilitation of low-volume road intersections. Based on this background, the goals in this project are to achieve the following items:

1. Document the types of distress that are present in the field throughout Texas through surveys and site visits.
2. Categorize the sources and layers that contribute to the damage at intersections.
3. Develop maintenance and rehabilitation guidelines for intersections with problems.
4. Provide feasible design alternatives and remediation strategies to minimize cost without compromise performance.
5. Develop an interactive program to guide users through distress identification, remediation selection, and design procedures for low volume road intersections.

ORGANIZATION OF REPORT

Chapter Two contains a literature review with work related to this project throughout the United States and the rest of the world. Characteristics and mechanisms of the most common types of distresses of asphalt pavements and promising remediation strategies for such problems at different layers of the structure are described.

Chapter Three documents the extent of the problem and solutions in Texas. The results of district survey conducted at the beginning of this research are analyzed. The most prevailing low-volume road intersection distresses and their causes are identified. The survey also collected the different remediation methods utilized by Texas districts and their effectiveness. The input data for the design and methodology are also presented.

Chapter Four provides the methodology used in this project. The study explored the available approaches to preserve flexible pavement intersections and develop an expert system approach to allow for better and a more optimal preservation and rehabilitation strategies.

Chapters Five and Six present a forensic evaluation of one of the intersections investigated in this project followed by case study used to illustrate expert system tool. The intersection was examined using both destructive and nondestructive testing (NDT) combined with a condition survey. The result from the site investigation is used to demonstrate the use of the online expert system to select cost-effective remediation strategies for improving and preserving flexible pavements at intersections.

Chapter Seven provides the presentation of results for the intersections at the sites that were investigated and the outcome of the expert system recommendations. Finally, Chapter Eight includes a summary of findings, conclusions as the results of this research.

CHAPTER 2 - REVIEW OF LITERATURE

A substantial literature review that documented strategies to preserve and rehabilitate flexible pavement at intersections is incorporated in this report. The report is organized starting with a review that is focused on most common flexible pavement distresses at intersections. Next, a review of current TxDOT specifications for flexible pavement rehabilitation is documented. What is followed is a set of summaries of the flexible pavement at intersection specifications adopted by several organizations and state agencies. Also incorporated is previous research by agencies and strategies to stabilize and remediate base and subgrade problems.

BACKGROUND

A vast majority of the TxDOT highway system consists of secondary roads that are constructed with thin pavement structures and thin hot mix asphalt surface or two-course surface treatment. This network of low-volume roads has served the public well, and for the most part, performs satisfactorily with periodic maintenance. One of the weakest links in this network is the performance of the pavement at the intersections. Severe permanent deformation (pushing, shoving and rutting[1]) have been reported at intersections of some of these low-volume roads while pavement sections constructed with the same materials adjacent to the intersection perform adequately. These failures occur because of the higher severity of loads exerted to the pavement at the intersections.

COMMON TYPES OF DISTRESSES ON ASPHALT PAVEMENTS

Rutting

Rutting is defined as the longitudinal permanent deformation or plastic movement of the asphalt pavement under the action of repeated loadings over the wheel path. Rutting is usually caused by the densification and shearing of the different pavement layers. It is visually identified by the depression in the pavement surface along the wheel paths. Even though visible on pavement surface rutting may occur on any of the layers.

[1] In this report the term permanent deformation is used to imply to rutting as well as shoving and pushing.

Rutting is a serious safety issue for drivers. When water accumulates in the ruts, there is a potential for hydroplaning. The hydroplaning phenomenon consists of the buildup of a thin layer of water between the pavement and the tire and results in the tire losing contact with the surface, with the consequent loss of steering control (Yoder and Witczak, 1975).

Three main mechanisms lead to the following three types of rutting: Structural Rutting, Instability Rutting and Surface/Ware Rutting. It is important to differentiate between these three types of rutting and their potential causes. Different mechanisms lead to a variation in visual characteristics of rutting. According to Fang (2001), shapes of transverse surface profiles differ between failures in the HMA surface mixtures and failures in the underlying support layers.

Structural Rutting

The deformation of one or more layers underlying the HMA layer results in structural rutting. Base and/or subgrade materials are unable to sustain the load stresses resulting in depressions and lack of support to the superior layers, manifesting on surface rutting.

A cross sectional diagram of structural rutting is shown in Figure 2.1. Structural rutting can be visually identified rather easily. Two main characteristics distinguish structural rutting from other modes of rutting. Structural ruts are wide and do not have humps on their sides as compared with instability rutting described later.

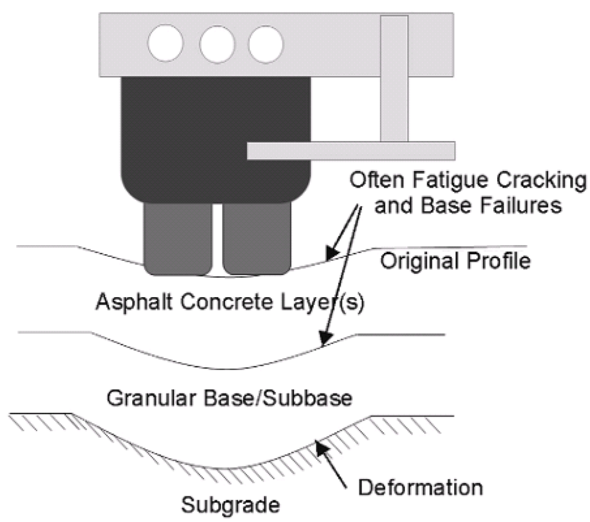
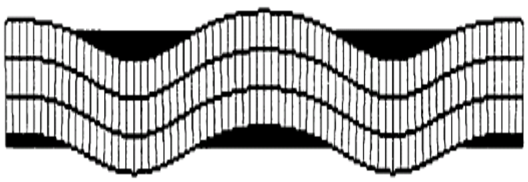


Figure 2.1 - Structural Rutting on Asphalt Pavements (Federation of Canadian Municipalities and Canadian National Research Council, 2003).

The surface deformation is dependent on which of the layers is failing to support the load. The visual characteristics will be different when the subgrade is failing as compared to the base. Figures 2.2 and 2.3 illustrate and compare the difference between the surface deformation profiles due to base and subgrade failures. When the base is failing, a small hump will be visible at the surface in the middle of the two wheel paths, while the deformation due to subgrade failure will have no humps at all with a wider wheel path depression (Fang, 2001).



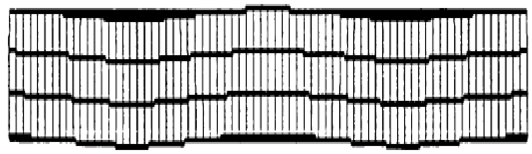


Figure 2.2 - Surface Deformation Due to Base Deformation. (Fang, 2001)

Figure 2.3 - Surface Deformation Due to Subgrade Deformation. (Fang, 2001)

Inadequate design, poor construction, and improper material specification in asphalt pavement systems generally cause structural rutting. Traffic conditions, weak substructure, or even poor drainage are essential parameters in pavement design. Misestimation of these parameters leads to inadequate design and affect the pavement system which could induce structural rutting.

Instability Rutting

Instability rutting or plastic flow is the type of rutting that is due to inadequate HMA mix design rather than the structural design. Epps (1999) reported that the shear deformation, rather than densification, is the primary rutting mechanism in HMA surface mixtures when the supporting layers are reasonably stiff. This kind of rutting is visually recognized by the humps formed on the sides of the rut as shown in Figure 2.4.

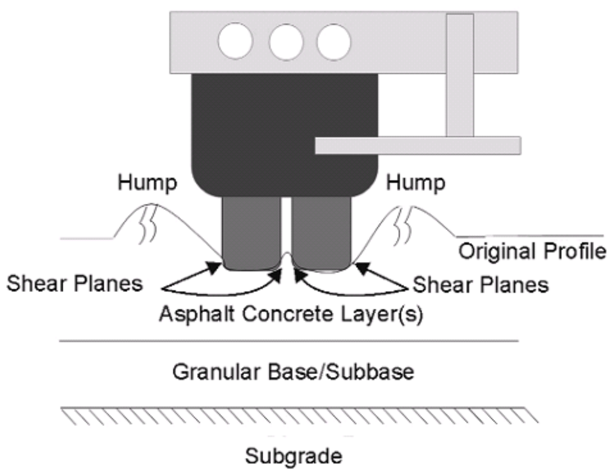


Figure 2.4 - Instability or Plastic Flow on Asphalt Pavements (Federation of Canadian Municipalities and Canadian National Research Council 2003).

This type of distress is more visible in slow trafficked area of the pavement such as intersections which represent a variance in the loading conditions applied to the pavement. Braking, accelerating, turning, standing, and slow moving stresses at intersections induce instability rutting. It may also be contributed to factors such as:

- High pavement temperatures.
- Improper materials.
- Rounded aggregates.
- Too much binder and/or filler.
- Insufficient or too high air voids.

According to Colorado DOT Pavement Design Guide (2009), during warm summer months the sun radiation and the exhaust of the slow/standing vehicles raise the pavement temperature. At higher temperatures a reduction in the HMA stiffness occurs, which may induce instability rutting in the HMA layer. Dripping engine oil and other vehicle fluids are also concentrated at intersections and tend to soften the asphalt (CDOT, 2009). At intersections, stopped and slow moving traffic allow exhaust to elevate asphalt surface temperatures even higher. A properly designed mixture with a stiffer asphalt binder and strong aggregate structure will resist plastic deformation of the hot mix asphalt pavement.

Surface/Wear Rutting

Wear rutting is the consolidation in the wheel paths of the HMA layer due to insufficient compaction effort which is usually reflected in not achieving the target density. Consequently additional compaction to the asphalt layer is generated by vehicle loading without any base/ subbase yielding or the formation of HMA humps as seen in Figure 2.5. According to the Colorado Department of Transportation (2009) the following list of factors contributes to this type of rutting:

- Insufficient compacting effort within the lower base layers
- Not enough roller passes while paving
- HMA cooling before target density
- Asphalt moisture or dust
- Low asphalt content in the mix
- Lack of cohesion in the mix (tender mix, gradation problem)

Wear rutting is also the result of chains and studded tires wearing away the pavement surface during winter season. This problem is not common in Texas.

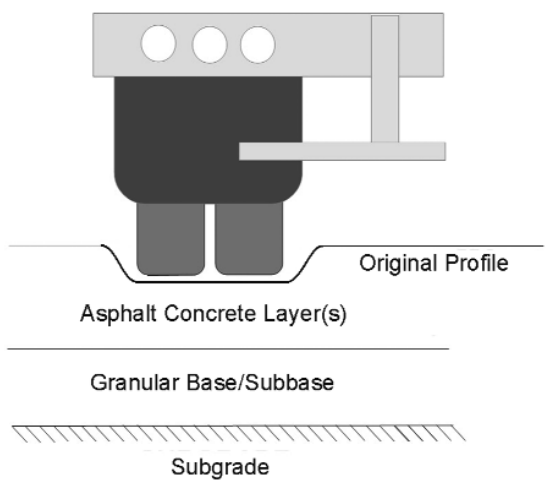


Figure 2.5 - Wear Rutting on Asphalt Pavements (Federation of Canadian Municipalities and Canadian National Research Council 2003).

Shoving

Shoving of an asphalt concrete pavement is defined as the longitudinal surface displacement of the HMA. Shoving is usually caused by an unstable asphalt layer that is not strong enough to resist horizontal stresses. Acceleration and deceleration of vehicles represent a continuous load in the same direction that generally causes shoving as shown in Figure 2.6. Excess binder in the mix, mistakes on the gradation, and erroneous temperature during compaction are parameters that cause a weak asphalt mixture. These potential problems along with poor bonding between the HMA and the underlying layer decrease the resistance to horizontal stresses leading to shoving. Shoving can be easily identified by distortion of pavement markings, and vertical displacements (dips and bumps). In many cases shoving is manifested with a large "bow wave" in front of the braking section or areas where HMA abuts a rigid object such as utilities. Shoving affects ride quality and may represent a safety hazard.

Figure 2.6 - Shoving on Asphalt Pavements.

Fatigue Cracking

Fatigue in asphalt pavement manifests itself in the form of cracking from repeated traffic loading (Suo et. al., 2007). Three main factors that affect the initiation and propagation of fatigue cracking are the mix design, pavement structure, and construction procedures. The main visual characteristics of fatigue cracking are the interconnection of cracks in a chicken wire/alligator pattern as seen on Figure 2.7.

Fatigue cracking is an important mechanism in the deterioration of asphalt pavement because of the harmful effect this cracking has on the stiffness and strength of pavement. Cracking allows water to percolate to the underlying layers, weakening the support and therefore accelerating permanent deformation of the pavement sections.

Other Distresses

The dominant distresses at intersections are rutting, shoving and fatigue cracking, however other distresses may manifest at the intersections. The sources of the dominant distresses can also generate additional distresses and the distresses themselves can represent a source of other distresses. Such is the case of moderate to high severity fatigue cracked areas, where the interconnected cracks form pieces that when moved while subjected to traffic leave a Pothole behind. Another surface defects such as bleeding, raveling and polished aggregates are

Figure 2.7 - Fatigue or Alligator Cracking on Asphalt Pavements.

distresses present at intersections which according to the LTPP "Distress Identification Guide" (2005) are potential mixture related performance problems.

REMEDIATION STRATEGIES OF ASPHALT PAVEMENT AT INTERSECTIONS

An extensive review of the literature indicates that the sources of and solutions for failure of the intersections in urban areas are well researched and a number of solutions (e.g., full-depth concrete slabs, whitetopping, high quality HMA overlay etc.) have been implemented. For example, the National Asphalt Pavement Association (NAPA) and the American Concrete Pavement Association (ACPA) have several documents and training materials available for this purpose. On the other hand, less attention has been focused intersection on the rural low-volume road in the US. In many countries in Africa and Southeast Asia, and in Australia and New Zealand the majority of their highway networks are either unpaved or are only covered with surface treatment. Much can be learned from their operations and incorporated into this research. In this section a review of international strategies is presented. The strategies and operations from this collection of work will help provide the initial framework for developing implementable solutions for the rural.

Current TxDOT Specifications for Flexible Pavement Rehabilitation

TxDOT's Flexible Pavement Rehabilitation methods are listed in the TxDOT Pavement Design Guide (2006) found in http://onlinemanuals.txdot.gov/manuals/. According to such guide developing a rehabilitation design generally requires extensive investigation into the condition of the existing pavement structure, performance history, and laboratory testing of materials to establish suitability of existing and proposed materials for use in the rehabilitation design. The field investigation will require a deflection survey, drainage survey, and perhaps additional nondestructive testing (NDT) surveys such as ground penetrating radar (GPR), dynamic cone penetrometer (DCP), and seismic. Examination of multi-year Pavement Management Information System (PMIS) distress and ride data will show performance related issues. Once these preliminary surveys are conducted, locations for material sampling can be established. In addition, for projects where full-depth reclamation is being considered, samples of the structure should be taken at intervals not to exceed 0.5-mi. These samples will be evaluated in the lab to verify field survey conclusions and establish basic properties necessary to quantify moisture susceptibility, stabilizer compatibility, blending requirements, etc.

The preferred rehabilitation strategy should:

- be cost-effectiveness
- address the repair of the specific problems of the existing pavement
- prevent of future problems, and
- meet all existing constraints of the project.

TxDOT currently does not have a specific strategy to approach problems with flexible pavement at intersections; therefore such problems have been approached with regular road procedures, even though intersections represent a different situation. The outcome of this research study is to provide at minimum a handbook designed for maintenance personnel showing "best practices" for maintaining flexible pavements at intersections and an expert system that allows for selecting the optimal remediation strategy at intersections.

Asphalt Institute

Knowing that pavement at intersections require special attention due to their high-stress conditions, the Asphalt Institute (AI) published a set of articles named "Intersection Strategy" (Walker and Buncher, 1999). These articles include guidelines to diagnose the sources of the pavement distress and to select the proper methods to repair them. Different agencies have adopted the AI strategies and/or developed guidelines that are similar to them. The Plant Mix Asphalt Industry of Kentucky (PAIKY), Asphalt Pavement Alliance (APA), Maryland Asphalt Association and the National Asphalt Pavement Association (NAPA) are among the agencies that follow the AI strategy. States such as Oregon have also adopted the strategies promoted by the AI in their Pavement Design Guides. Canada's strategy goes along with the Asphalt Institute's as reflected in their 2003 publication entitled "Rut Mitigation Techniques at Intersections."

The intersection strategy consists of the following four steps to minimize distresses and rehabilitate intersections.

1. Evaluate Performance Problems and Causes
2. Ensure Pavement is Structurally Adequate
3. Select appropriate Materials Selection and Mix Designs
4. Adapt proper Pavement Construction Techniques and Selection of Rehabilitation Method

Each step is described below.

Evaluate Performance Problems and Causes

The main concern at HMA intersections is the presence of rutting owed to a weak mix or higher than normal stress conditions. Identification of rutting problems at intersections can be through user complaints, staff inspections, or visual and/or measured monitoring. A forensic investigation is the key to find the root of the problem. It is important to monitor the pavement surface condition to establish the rate of deterioration.

A visual inspection of the pavement surface conditions should be the first step to initiate a forensic study. It should be performed by a pavement engineer who has experience in identifying distresses in pavements. It is important that the location (lane), extent (distance the rutting extends before and after the intersection), and severity of the rutting are established.

After identifying the severity, an evaluation of the causes should be carried out. The evaluation of any roadway that may need rehabilitation may include:

- Deflection testing (FWD, Dynaflect, or Benkelman)
- Coring pavement and subgrade samples
- Thickness measurements for all layers of the pavement
- Determination of material properties of the subgrade, granular base and asphalt concrete
- A review of the construction and maintenance information.

The findings are then analyzed to determine the type (or types) of rutting that has occurred and its causes, to determine the most appropriate rut mitigation strategy.

The analysis of the pavement structure will allow for determining the type or types of distresses present at the intersection, and help choosing a rehabilitation strategy from the following alternatives:

- Pavement preservation (e.g., with low severity instability rutting);
- Pavement overlay (e.g., with medium severity instability rutting);
- Pavement rehabilitation (e.g., with high severity instability rutting); or
- Pavement reconstruction (e.g., with pavement structural rutting).

A life cycle cost analysis should be performed to select the most cost-effective method.

Ensure Pavement is Structurally Adequate

An intersection pavement system must provide the structural capacity to withstand the traffic conditions. A proper structural design must take into account the subgrade strength, base thickness and traffic. The middle of the intersection receives loading from several approaches and should be considered in the traffic evaluation. Overlaid, rehabilitated, or reconstructed existing pavements must have structural adequacy for current and anticipated future traffic loads (ESALs). For existing pavements, the structural capacity of the in-place materials must be checked, and any failed or weak areas removed or replaced (Buncher, 2002; Walker and Buncher, 1999). A new design has to be carried out. Replacing the asphalt with the same mix design or paving on top of existing failed pavement will most likely result in recurring failure.

Appropriate Materials Selection and Mix Designs for HMA

The long term performance of an asphalt pavement is dependent on the stiffness of the asphalt binder and the characteristics of the aggregates. The binder's stiffness plays a critical role in the permanent deformation resistance of an asphalt pavement. So is the shape and strength of the aggregates, which combined represent the skeleton providing strength from stone-to-stone contact. The binder should be stiff enough to prevent rutting while the aggregate must be angular to ensure a better aggregate interlocking and bonding than rounded aggregates.

The use of the Superpave's Performance Grade (PG) binder system is highly recommended. The PG system selects a binder based on its ability to perform at the temperatures to which the pavement will be subjected. It is a common practice for slow moving design loads to "bump up" the binder one grade, and for standing loads two grades. According to previous experiences at numerous sites across the United States, PG 76-XXs should perform well at intersections (Buncher, 2002). Table 2.1 indicates the Superpave binder selection adjustments for different ESAL and loading rates.

The aggregate structure carries the load and the shearing forces while the binder holds it together. A proper aggregate selection and gradation is essential. A strong, coarse, and angular aggregate with multiple faces will provide more internal friction and create an aggregate matrix that will resist better the shearing forces that lead to rutting. The amount of rounded aggregates should be limited.

A rut-resistance mixture that has proven to be of great reliability for intersections is Stone Matrix Asphalt. This gap-graded mixture relies on stone-to-stone contact and can be a good option to be applied as a base mixture.

Table 2.1 - Superpave Binder Selection Adjustments for Design ESALs and Loading Rate.

Design ESALs Million	High Temperature Grade Increase in 6 °C Grade Equivalents		
	Heavy Traffic (Trucks and/or Buses) Loading Rate (Speed)		
	Standing < 20 km/hr	Slow 20 to 70 km/hr	Standard > 70 km/hr
< 0.3	-	-	-
0.3 - < 3	2	1	-
3 – 10	2	1	-
10 - < 30	2	1	-
≥ 30	2	1	1

Proper Pavement Construction Techniques

The performance of any pavement is highly dependent on the pavement construction techniques followed, and the quality of construction achieved. Proper construction techniques include the following.

- Prepare the substrate properly. Thoroughly clean old or milled surfaces, remove any old patches or thin asphalt concrete areas that may debond, and uniformly tack prepared surfaces at the appropriate application rate.

- Produce, place, and compact hot-mix asphalt at appropriate temperatures (i.e., avoid overheating).
- Avoid segregation with proper aggregate stockpiling, and hot-mix asphalt production, transportation, and placement techniques.
- Place a uniform and smooth mat.
- Construct transverse and longitudinal joints properly for durability and to prevent the ingress of water.
- Achieve the compaction (density) requirements.
- Follow an appropriate quality control plan to achieve the proper construction techniques and overall quality.

Selection of Rehabilitation Method

The rehabilitation method selection for a rutting problem at an intersection should be based on a life cycle cost comparison analysis. Any pavement used for rehabilitation should follow the recommendations above.

<u>Mill and Overlay with Asphalt Concrete</u>

Resurfacing is the most common rehabilitation method for flexible and composite pavements. It is necessary to mill a superficial portion of rutted asphalt pavement, and then replace a surface layer of the pavement with rut-resistant HMA. An intimately bonded interface between the milled surface and the HMA overlay has to be ensured. It has to be clean, any loose material has to be removed a properly tack coat needs to be placed in between.

<u>Rut Filling Using Spray Patching, Thin Overlays, or Micro-Surfacing</u>

On wear rutting and low severity instability rutting, the wheel path ruts can be filled by spray patching, or by micro-surfacing, and/or tacking, as necessary, before the HMA overlay/micro-surfacing. Spray patching is appropriate for lower volume, rural or surface-treated pavements. Rut filling should only be viewed as a relatively short-term mitigation measure.

<u>Grinding and Precision Milling</u>

This procedure can be used to restore the surface texture and profile of pavement, when medium severity instability rutting is present. It consists of removing the rutted surface of the concrete to the rutting depth. It offers a short-term solution to instability rutting.

<u>Whitetopping (Conventional and Concrete Inlay)</u>

Whitetopping is defined as the construction of a new Portland Cement Concrete (PCC) over an existing flexible pavement. Whitetopping can be a technically and cost-advantageous rehabilitation alternative for badly deteriorated asphalt concrete at intersections, particularly for flexible pavements exhibiting instability, rutting, shoving, and alligator cracking (Smith et al, 2002).

The interface between the old asphalt pavement and the new PCC overlay may be a milled surface, a HMA leveling course, or direct placement (no treatment at all). Conventional whitetopping is generally suitable for the traffic loading associated with all classes of roads intersections. PCC is designed as if it was on a treated base course.

Ultra-Thin Whitetopping

A thin layer of PCC is placed over a prepared distressed flexible pavement. The deteriorated asphalt concrete surface is cold milled to enhance the bond between the PCC and asphalt concrete. Ultra-thin whitetopping is intended for parking areas, urban streets, bus bays, and intersection flexible pavements where instability rutting is a problem, but no other significant deterioration is present (ACPA, 1998; Smith et al., 2002). The UTW is generally intended for flexible pavements subject to lower volumes of heavy traffic (Smith et al., 2002).

Thin Composite Whitetopping (TCW)

TCW is defined as "a concrete overlay intentionally bonded to an existing asphalt pavement to create a composite pavement section. Joints are spaced at close intervals to reduce stresses in the concrete overlay (Cole et al, 1997). This is an emerging technology and it is intended for high volume roadways. Pavement thickness is based on engineering judgment and performance of previously placed TCW pavement installations.

Roller Compacted Concrete (RCC)

Roller compacted concrete is a very dry zero-slump cement-aggregate mixture with supplementary cementing materials so that it remains stable for compaction by vibratory rollers like those used for asphalt pavement compaction.. Asphalt pavement is placed over the RCC to provide a smoother ride for the driving public.

Interlocking Concrete Pavements

Concrete pavers are placed in a herringbone pattern and vibrated into a 25 mm layer of screened bedding sand conforming to the grading requirements. Dry joint sand is then swept into the joints and vibrated with a plate compactor until the joints are full. A geotextile fabric is placed over the milled asphalt prior to placement of the bedding sand and concrete pavers.

Hot in Place Recycling (HIR)

The Colorado DOT Pavement Design Manual (2009) indicates that the HIR should be used to fix surface distresses when the cause of the problem is not structural, but merely from the upper asphalt layer, such as cracking and minor rutting. The process is performed by heating and mixing equipment which preheats the asphalt to soften it and then mills it so it can be mixed with binder, new aggregates, or any other additives to be finally re-compacted. The main benefit from this process is the conservation of both materials and energy by recycling on site.

Cold in Place Recycling (CIR)

CIR is defined as a rehabilitation technique in which the existing pavement materials are reused in place. The CIR process usually uses 100% of the reclaimed asphalt pavement (RAP) without the application of heat for the recycling process. CIR can be useful in eliminating rutting within a range of 2 to 4 in. in depth, eliminate potholes, rough areas and restore the design profile. Although cold recycled mixes can produce stable surfaces, a wearing surface over the recycled mix is normally required.

Canada

The Federation of Canadian Municipalities and Canadian National Research Council (2003) "Rut Mitigation Techniques at Intersections" has a comprehensive guideline for rehabilitation of intersections. Figure 2.8 provides the flowchart of their activities to address the instability rutting at intersections. The flowchart of activities displays how important is the communication and feedback between the different levels of design. The process starts with analyzing the pavement performance by identifying the type of distresses and the sources of the problem. With loops through the design procedures it aims to ensure structure adequacy and meanwhile trying different rehabilitation methods starting from the most economical targeting cost-effectiveness.

Colorado Department of Transportation (CDOT)

The CDOT present a slight variation on addressing strategies at intersections. The Colorado Pavement Design Manual (2009) considers the intersections separately since they hold merged traffic directions over a same pavement section. As a result, the number of vehicles from each of the intersecting roads is accumulated and thereby exceeding the traffic design of each of the roads. Another factor they consider is the drainage within intersections, since improper drainage can lead to moisture damaging the pavement and saturating the so underlying base and subgrade layers leading to lack of support and thereby deformation of the complete pavement structure.

The keys used by CDOT for proper scoping of the projects are the following:

- Identify the problem with existing intersection.
- Remove enough pavement layers to find the problem.
- Design and reconstruct with a high performance HMA mix especially formulated.

Colorado DOT design asphalt pavements for a period of at least 20 years and for restoration and resurfacing of 10 years. General considerations by CDOT to design a HMA intersection include the following:

- Heavy truck and high volume traffic intersections require extra considerations in their design and construction. High performance intersection design should be considered when 20-year traffic loading of the two traffic streams add up to one million ESALs or more.

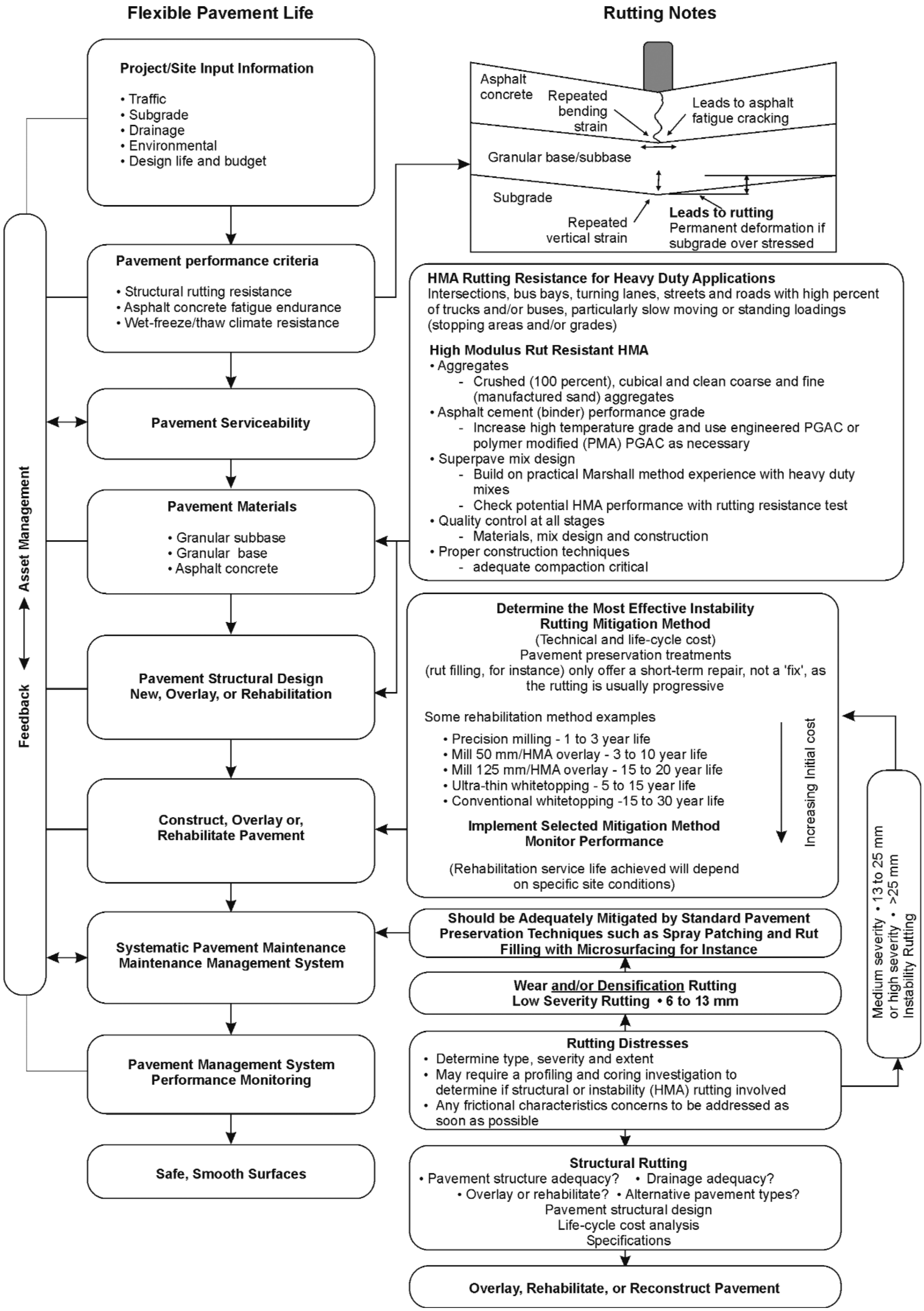


Figure 2.8 - Flowchart of Activities for Mitigating Intersection Rutting.

- Intersection pavements suffer from slow traffic and sharp turns, and such factors must be included in the design. The road is also vulnerable to deceleration and acceleration of vehicles approaching an intersection. A stronger transition pavement should be applied before and after every intersection. If there is two-way traffic, the transition should extend 300 feet on both directions. When one-way traffic, transition should be at least 300 feet on the deceleration side and 100 feet on the acceleration side of the intersection.
- A PG 76-28 binder is suggested by the Colorado DOT for intersection pavement. Bumping grades would improve performance of asphalt. Superpave procedure to select binder grade for asphalt intersections is recommended.

Australia

The Australian Asphalt Pavement Association (AAPA) provides the advisory note 15 for "Bituminous Surfacing for Intersections on Light & Medium Duty Flexible Pavements" (1999) as a guide to utilize sprayed seals and other bituminous treatments over unbound and lightly bound granular pavements, especially in rural areas. A Spray Seal (Chip Seal in the US) is done by spraying a layer of binder on top of a damaged road surface and then covering it with aggregate. The binder waterproofs the pavement while the aggregate provide extra damage protection to the pavement. Sprayed seals provide an effective and economical resurfacing alternative in a large number of situations, but the turning and braking of heavy vehicles at intersections grind away the surface aggregate inducing the bleeding of the seal.

The performance of the sprayed seals can be improved by different methods, but substituting the sprayed seal with a thin layer of HMA can improve smoothness and appearance, representing a longer term cheaper alternative. Performance of sprayed seals for high stress situations can be enhanced by:

- Polymer Modified Binders (PMB): also called High Stress Seals (HSS). They help boost binder cohesion, toughness and improve temperature resistance.
- Multiple applications of binder and aggregate: produce a stronger sprayed seal. With two applications of aggregate, the second one being half the size of the first one. This will allow the smaller aggregate to accommodate within the void left by the larger aggregate, providing a better clutch and therefore a stronger structure against vehicle shearing forces.
- Multiple application of aggregate ("racked in" or "dry lock" techniques): light application of a small size aggregate (5 mm) over a coarser aggregate sprayed seal. This in order to prevent the coarse aggregates from rolling away during seal compaction.

Asphalt

Guidelines for asphalt surfacing come for intersections and roundabouts are as follows:

<u>Lightly Trafficked Pavements</u>

The surface of the pavement has to be primed before all. For clean and in good condition primed surfaces tack coat may not be necessary, so it may be either reduced or discarded. A dense surface finish and durability are the main requirements. Small aggregate size, fine texture and workable mixes are usually used

Medium Trafficked Pavements

They are commonly used over sprayed seal pavements, but applied to high stress sections such as intersections, roundabouts and median openings. Cutters and oils in the seal have an effect on asphalt, causing bleeding. If possible, time need to be given to the seal to allow compaction under traffic and cutters to evaporate before any asphalt surfacing is performed. Time will also help to identify the surface weaknesses of the pavement. Mix design has to be developed according to the road requirements. In Australia 10 or 14 mm size dense graded asphalt mixes are used for most medium to heavy traffic conditions.

New Zealand

New Zealand has a supplementary document to the Austroads "Pavement Design – A Guide to the Structural Design of Road Pavements" (2004) which considers the high lateral stresses induced at intersection and thereby requires attention while designing and constructing all the layers in a pavement structure. Intersections are exposed to loading from different directions and this parameter should be considered in the design. Intersection must extend into the approach road by an appropriate distance

For structural adequacy, the thickness and configuration of each layer has to satisfy the critical strain criteria. In case of a flexible pavement at the intersection, elastic deflection (based on the Benkelman Beam) must not exceed an acceptable level of approximately 1mm to prevent fatigue cracking.

The upper pavement materials must have high shear strength in order to resist the high levels of shear stress applied on the pavement surface as a result of vehicles slowing down, accelerating, breaking, and cornering at intersections. The use of structural asphalt, concrete or modified aggregate materials should be considered by New Zealand personnel. In New Zealand, Stone Matrix Asphalt (SMA) has shown very good performance in terms of shear resistance and favorable surface properties.

Illinois DOT

The Illinois Department of Transportation Pavement Design (2002) contains specific criteria to classify high-stress intersections and thereby select the required materials. High-stress intersections are defined as those under stop control, either signal or sign that have one or more of the following conditions:

- The approach grade on any stop-controlled leg of the intersection is greater than or equal to 3.5%.
- The two-way Average Daily Traffic (ADT) for Multiple Unit (MU) vehicles is greater than or equal to 400 vehicles in rural areas or 800 vehicles in urban areas. For ramps and other one-way facilities, use one-half of this ADT criterion.

- The ADT for turning MU vehicles on any one leg of the intersection is greater than or equal to 200 vehicles in rural areas or 400 vehicles in urban areas. This also applies to sharp turning movements that are not under stop control.

The materials for intersection pavement are chosen depending on the existing pavement and the traffic conditions at the location. Pavement types for high-stress intersections are limited to either PCC; or AC Superpave Ndesign $\geq$ 90.

The pavement materials for high-stress intersections have to be used for a minimum distance of 150 ft from the stop sign. Such length may be extended if a traffic study indicates it.

Complete reconstruction, instead of resurfacing, of an existing distressed pavement at an intersection should be considered in case of present rutting and/or shoving.

Intersections not meeting the mentioned criteria are not considered high-stress intersections. Still they can develop similar signs of permanent deformation as those on the high-stress intersections. Non-high-stress intersections paved with PCC pavement may use PCC for repair if the improvement consists of minor widening without resurfacing.

Non-high-stress intersections with asphalt pavement showing signs of permanent deformation (rutting, shoving) should be examined to determine the source of the problem. An evaluation of the complete structure must be performed to determine what material might be inadequate. Such material has to be removed and replaced before any resurfacing. In case that the mixture results to be stable but the problem persists, then an exception to the criteria should be considered. Example exceptions include:

- Lower urban ADT for MU vehicles if all are required to stop or if the approach speed is greater than 40 mph;
- Lower urban and rural ADT for MU vehicles if the majority are fully loaded at intersections near warehouse facilities, landfills, grain elevators, etc.;
- Demonstrated problems with shoving of a bituminous overlay related to tight turning movements; and
- Including SU trucks in the MU truck count where the SU vehicles are primarily fully loaded hauling vehicles (e.g., grain trucks, concrete trucks, coal trucks).

Hot Mix Asphalt Mixtures for Nevada's Intersections

The Nevada Department of Transportation (NDOT) uses a coarse dense gradation HMA which has successfully resisted rutting under normal highway traffic loading throughout the entire state. However, the performance of the mixture at the intersection has been inadequate.

A research project to investigate and develop specific requirements for hot mix asphalt mixtures at intersections was conducted by Hajj (2007). This study evaluated the Asphalt Pavement Analyzer (APA), the Repeated Shear at Constant Height (RSCH), and the repeated load triaxial test (RLT) as potential candidates for a mix design test for intersection mixtures in addition to the triaxial compression strength test (Hajj, 2007). Hajj proposed a new list of recommendations to assess permanent deformation for intersections and stopping areas as follows:

- RSCH: maximum of 1.9% permanent shear strain at 158°F after 5,000 cycles.
- RLT: maximum of 2.0% permanent axial strain at 158°F after 12,000 cycles.
- APA: maximum of 0.06 inch at 140°F after 8,000 cycles.

National Center for Asphalt Technology

Kandhal (1998) conducted a field investigation to determine the cause of rutting at intersections. A list of considerations to minimize permanent deformation is collected through a literature search by Kandhal are as follows:

1. Lower Asphalt Content: Higher asphalt content is needed for improved fatigue life and durability of the asphalt mix, but it tends to enhance the rutting and shoving problems. The mix needs to be maximized for fatigue and permanent deformation through a compromise.
2. Coarser Gradation: Finer gradations or over-sanded mixes are more susceptible to permanent deformation.
3. Angular and Rough Textured Aggregate: This is especially applicable to the fine aggregate fraction. It has been demonstrated by Kalcheff and Tunicliff (1982) and Brown and Cross (1992) that mixtures utilizing angular manufactured sand are more resistant to permanent deformation than mixes produced with rounded or sub-rounded natural sand.
4. Increased Air Void Content: Mixtures with low voids in the mineral aggregate (VMA) and higher asphalt contents have a tendency to have very low air void contents after densification by traffic. Such mixtures lose stability after reaching a critical compaction level and start to rut and shove.
5. Higher Viscosity Asphalt Binder: An asphalt binder with a high viscosity at 60°C will be more resistant to horizontal thrust as far as plastic flow in a mix is concerned compared to a low viscosity asphalt binder.
6. Higher Fines Content: Increase in the minus 75 microns fraction of the mix will tend to stiffen (increase the viscosity) the binder.
7. Larger-Size Aggregate: At proper asphalt content larger-size aggregate (such as 19.5 mm) mix in the wearing course tends to be more resistant to permanent deformation.
8. Reduced Overlay Thickness: If the existing pavement is structurally sound (for example, Portland cement concrete), thicker asphalt mix overlays are unnecessary in the critical areas like intersections. Thinner overlays (for example, binder course can be eliminated) in these areas will minimize the problem.
9. Improved Bond between Pavement Layers: A lack of good bond between the pavement layers (especially in top 150 mm of the pavement) can cause slippage due to horizontal thrust.

The following mixtures were recommended by Kandhal (1998):

- 2 in. Stone Matrix Asphalt (SMA) wearing course (nominal maximum size 12.5 mm)
- 2 in. Stone Matrix Asphalt (SMA) binder course (nominal maximum size 19.0 mm)
- 2 in. mm dense-graded large stone mix base course (nominal maximum size 25 mm)

REMEDIATION STRATEGIES CONSIDERING SUBSURFACE LAYERS OF PAVEMENTS

Base Layer

Structural inadequacy can be cause by subsurface layers as much as the HMA layer. Therefore, it is of utmost importance to identify the layer(s) that contribute to the excessive permanent deformation of the intersections. If the base layer is the contributing factor to distress, treatment of the top layer does not solve the problem. The remediation strategy needs to address the base layer. Most of the time the base layer is under designed and the can be easily remedied by stabilization and modifying the gradation.

Stabilization is achieved by adding proper percentage of additives such as cement, lime, fly ash, bitumen, or combinations of these materials to the base. The selection of the type and determination of the percentage of additive are dependent upon the soil classification and the desired degree of improvement. Generally, smaller amounts of additives are required to modify soil properties such as gradation, workability and plasticity. Larger quantities of additives are used to significantly improve the strength, stiffness and durability (Army TM 5-822-14, 1994). Spreading and compaction are achieved by conventional means after the additive has been mixed with the base. The most common improvements achieved through stabilization include:

- Reducing plasticity index
- Reducing swelling potential
- Increasing durability and strength
- Reducing dust during construction
- Waterproofing the soil
- Drying of wet soils
- Conserving aggregate materials
- Reducing cost of construction
- Providing a temporary wearing surface

The South African "Guideline on Low-Volume Sealed Roads" (2003) considers that the main objective of chemical stabilization is to enhance the suitability of locally available natural gravels for pavement construction, thereby avoiding the need to import other materials. This can often lead to a more cost-effective alternative for construction.

The selection of stabilizer type depends on the type of material present and their location in the pavement structure (Terrel et al., 1979). Table 2.2 provides varying stabilization methods for different materials. Coarse and fine grained soils, as well as clays are suitable for stabilization with Portland cement and lime-fly ash and lime. Typically, several criteria must be followed for the selection of a stabilizer. Figure 2.9 demonstrates a basic flowchart used by TxDOT for the selection of additive used for base treatment. Aside from the physical properties of the soil, TxDOT also considers the goals of the treatment, mechanisms of additives, desired engineering and material properties, design life, environmental conditions and economical factors.

Table 2.2 - Stabilization Methods for Different Soil Types (Terrel et al., 1979)

Soil Types	Most Effective Stabilization Methods
Coarse granular soil	Mechanical blending, soil-asphalt, soil-cement, lime-fly ash
Fine granular soil	Mechanical blending, Portland cement stabilization, lime-fly ash, soil-asphalt, chlorides
Clays of low plasticity	Compaction, Portland cement stabilization, chemical water proofers, lime modification
Clays of high plasticity	Lime stabilization

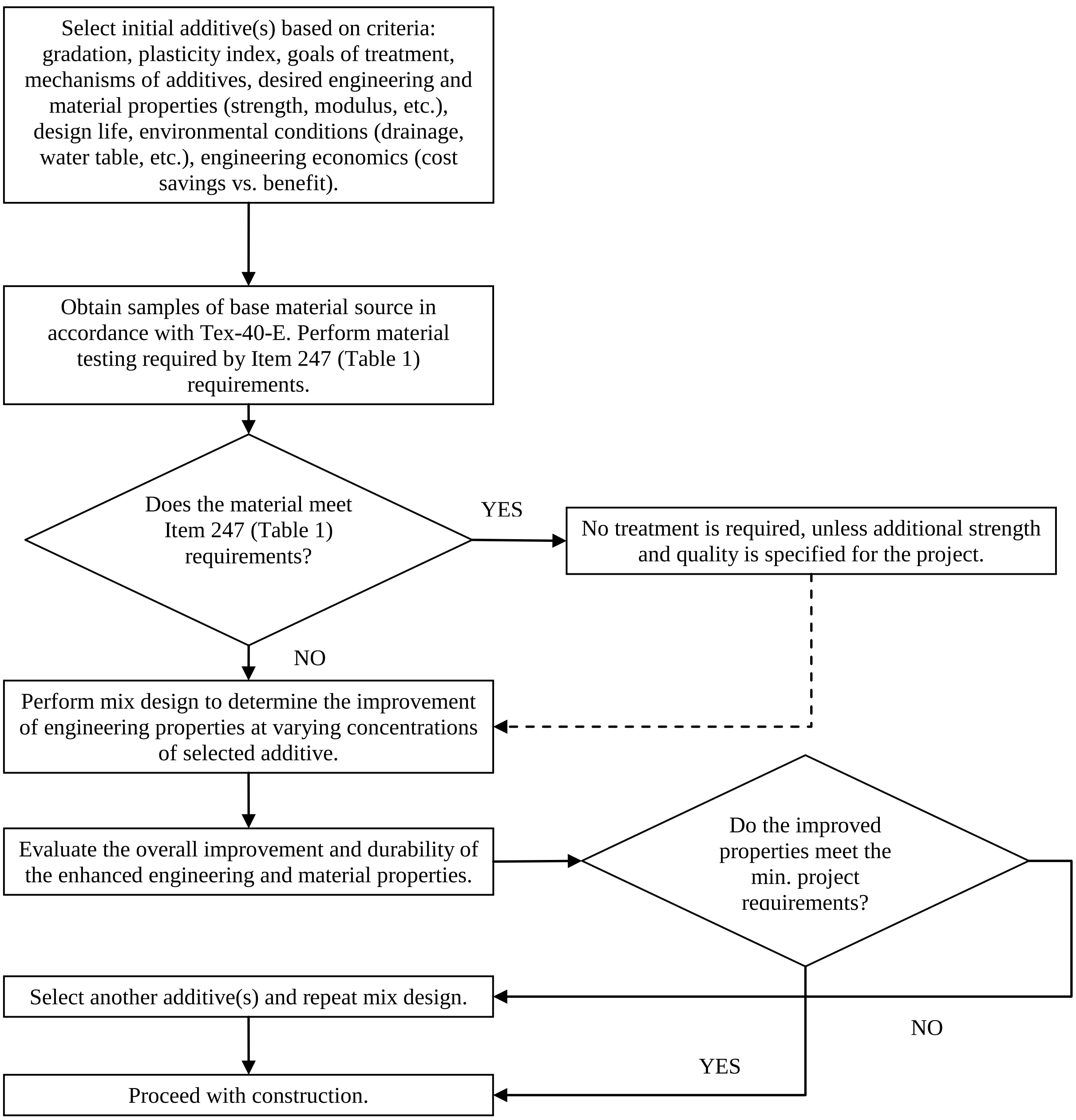


Figure 2.9 - TxDOT Flowchart for Base Treatment (TxDOT, 2005)

A simple mechanical stabilization alternative is exercised in South Africa often satisfies the specifications of a standard material. This alternative consists of blending two natural materials, gravel with sand, to form a mechanical stable layer by lowering the PI and optimum moisture content (OMC), and by improving the strength and the workability of the material.

A large variety of industry by-products and commercially produced additives is available for use in pavement stabilization, such as:

- Air-cooled blast furnace slag
- By-product lime
- Fly ash
- Ground granulated blast furnace slag
- Reclaimed asphalt pavement
- Recycled concrete material

Full-Depth Reclamation

Full depth reclamation (FDR) is a form of cold in-place recycling of flexible pavements. During this procedure, the hot mix layer and a predetermined amount of the underlying base course are pulverized simultaneously by special equipment. As a common practice, the two materials are mixed with stabilizing agents described above. Depending on the severity of structural problems of the original base course, additional virgin base material (add-rock) or RAP is sometimes mixed with the pulverized materials. The result of this process is an entirely new base material. Increasing shortages of virgin aggregate, rising fuel costs, as well as environmental concerns have led to an increased utilization of FDR in many states and countries. Like many other road rehabilitation procedures, FDR has both its advantages and disadvantages.

Recycling using the FDR process has many advantages which encompass a broad range of engineering concerns, from improving the economics of the project to safeguarding the environment. FDR facilitates complete reconstruction of a pavement system while utilizing all or most of the existing material. The process allows for grade corrections and small adjustments in road geometry, but more importantly, remedies structural pavement problems (Kearney and Huffman, 2000). The ability to utilize almost 100% of the existing materials reduces project costs associated with the transportation of virgin material to the site while concurrently eliminating disposal costs of the old aggregates. This is a great benefit for states such as Texas, where fresh aggregate is sometimes shipped from locations as far as Guadalajara, Mexico. Aside from the obvious economic benefits, FDR addresses “deeper” pavement problems as well.

Cracking and other defects are sometimes caused by inadequate base materials in flexible pavement systems. In these cases resurfacing of the road with another hot mix layer will not solve the problem. FDR can be implemented on these roads to strengthen the base materials (Kearney and Huffman, 2000). The new base that is formed from the combination of the existing pavement and part or all of the base material along with a stabilizing agent is often times stronger than the original materials. For this reason, roads that have undergone the FDR process are often considered to be structurally sounder than the original flexible pavement.

Since the pulverization process reaches deep into the base material, changes in the profile of the road are attainable during the FDR process. Epps (1990) states that significant pavement structural improvements can be made in horizontal and vertical geometry and without shoulder reconstruction. Old pavement profile, crown, and cross slope may be improved. This is possible since the entire layer of flexible pavement as well as part of the base is taken up. The advantages of FDR are not only limited to road improvements, it is also an environmentally sound choice for pavement rehabilitation as well.

With the strategy of "greener" roads being advocated by policy makers worldwide, FDR fits in as a viable solution to flexible pavement problems. The process as a whole conserves energy. Roads can be recycled in-place without any fuel being expended for heating of bituminous materials. Also, extra fuel is not required nor added emission produced during the transportation of new aggregate to the job site. This in turn leads to overall project savings in transport costs. In terms of aggregate, scarce supplies are not depleted for reasons of structural improvements.

Some problem areas have also been associated with the use of FDR. No comprehensive guidelines are currently in place that governs the implementation of the process. This has led to large variations in the results of such projects, even within the same state. Another concern with FDR is the curing time required for strength gain. Curing time is a major factor in the decision of when to let traffic back on that particular section of road. This in turn causes inconvenient disruptions in traffic. However, advances in equipment used for FDR has helped streamline the process so that road closures can be kept to a minimum (Epps, 1990). Also, the entire process is susceptible to climactic conditions, especially when asphalt emulsions are used as a stabilizing agent. Since the strength gain is dependent on the rate of moisture loss by the emulsion, it is not recommended that the process be carried out on days when heavy rainfall is expected.

Subgrade Layer

Ideally the subgrade should be strong and stiff enough to prevent excessive rutting. However, for fine-grained silt and clay soils, poor strength, high volumetric instability, and freeze/thaw durability problems are predominant. For expansive soil the volumetric change may be more severe and thus become a bigger challenge. The expansion action may result in intolerable differential heaving of pavements. Commonly used remediation methods can be categorized into two groups: (1) to improve strength and (2) to minimize moisture variation. In order to improve soft subgrade bearing capacity and strength, thick layers of granular material may be used on top of the problematic subgrade. In other instances, stabilization and geosynthetic reinforcement can be used. On the other hand, to minimize moisture variations and fluctuations, the commonly used strategies as summarized by Raymond and Ismail (2003) include:

- Treat the soil with lime or other additives to reduce expansion in the presence of moisture;
- Replace the material with a better material to a depth below which the seasonal moisture content will remain nearly constant;
- Provide an overlaying structural section of sufficient thickness to counteract the expansion pressure by surcharge;

- Stabilize the moisture content by minimizing the access of water through surface and subsurface drainage and use waterproof membrane such as rubberized asphalt membrane, geosynthetics. Put moisture barrier and/or remove nearby vegetation.

Admixture Stabilization

Admixture stabilization refers to mixing and blending a liquid, slurry, or powder with soil to improve soil strength and stiffness properties. Lime stabilization is a widely used means of chemically transforming unstable soils into structurally-sound construction foundations. Lime stabilization creates a number of important engineering properties in soils, including improved strength; improved resistance to fracture, fatigue, and permanent deformation; improved resilient properties; reduced swelling; and resistance to the damaging effects of moisture. The most substantial improvements in these properties are seen in moderately to highly plastic soils, such as fat clays (Little, 2000). Little (1999) claimed that lime stabilization often induces a tenfold stiffness increase over that of the untreated soil or aggregate. Croft (1967) found that the addition of lime significantly reduces the swelling potential, liquid limit, plasticity index and maximum dry density of the soil, and increases its optimum water content, shrinkage limit and strength.

Cement has been found to be effective in stabilizing a wide variety of soils, including granular materials, silts, and clays; byproducts such as slag and fly ash; and waste materials such as pulverized bituminous pavements and crushed concrete. These materials are used in pavement base, subbase, and subgrade construction (Little, 2000). It is generally more effective and economical to use it with granular soils due to the ease of pulverization and mixing and the smaller quantities of cement required. Fine-grained soils of low to medium plasticity can also be stabilized, but not as effectively as coarse-grained soils. If the PI exceeds about 30, cement becomes difficult to mix with the soil. In these cases, lime can be added first to reduce the PI and improve workability before adding the cement (Hicks, 2002). Addition of cement to clay soil reduces the liquid limit, plasticity index and swelling potential and increases the shrinkage limit and shear strength (Nelson and Miller, 1992).

Stabilization of soils and pavement bases with fly ash is an increasingly popular option for design engineers. Fly ash decreases swell potential of expansive soils (Ferguson 1993, White *et al.*, 2005a, b). Soils can be treated with self-cementing fly ash to modify engineering properties as well as produce rapid strength gain in unstable soils. Tests results show that fly ash increases the compacted dry density and reduces the optimum moisture content (White *et al.*, 2005a). Fly ash can also dry wet soils effectively and provide an initial rapid strength gain, which is useful during construction in wet, unstable ground conditions. Çoçka (2001) found that plasticity index and swell potential decrease with increasing fly ash contents. Ferguson (1993) noted that the decrease in plasticity and swell potential was generally less than that of lime because fly ash did not provide as many calcium ions that modify the surface charge of clay particles.

Lime and lime fly ash stabilized materials cure much slower, in general, than Portland cement stabilized layers. As with strength properties, resilient properties of lime-soil mixtures are very sensitive to level of compaction and molding moisture content. Lime-stabilization may substantially increase shear and tensile strengths. This strength increase provides a stiffer layer with improved load distributing capabilities. However, as the stiffness of the layer increases through the development of cohesion within the stabilized layer, the layer becomes more susceptible to load-induced tensile stresses that can lead to fatigue failure unless proper design steps are taken to reduce the potential of load induced damage. This is generally accomplished by ensuring that the layer thicknesses are such as to insure the development of acceptable flexural stresses within the stabilized layer. Typically the design parameter is the flexural tensile stress ratio. Thompson (1966) determined that the indirect tensile strength of lime-soil mixtures is approximately 0.13 times the unconfined compressive strength. Chou (1987) stated that the flexural tensile strength of lime-soil mixtures is approximately 0.25 times the unconfined compressive strength.

For sulfate rich soils, a phenomenon called sulfate-induced heave can happen that can severely reduce the long-term strength and durability of stabilized soil. Sulfate concentration can be determined in accordance to Tex-145-E. If the sulfate levels are above 3000 ppm, further recommendations and guidelines can be found in the 'Guidelines for Treatment of Sulfate-Rich Soils and Bases in Pavement Structures Soils' by TxDOT. Puppala *et al.* (2004, 2003) studied the effectiveness of sulfate resistant stabilizers such as cement Types I/II, V, lime mixed with fibers and Class F fly ash in providing better treatment of sulfate rich soils. Test results indicate sulfate-resistant cement provided the most effective treatment. The combined lime and fibers stabilization method provided the next best effective treatment. The Class F fly ash treatment provided low-to-moderate strength improvements that could be attributed to the low amounts of calcium present in this type of fly ash. On the other hand, the fly ash stabilization method was more cost-effective than the other methods. Kota *et al.* (1996) provide some suggestions to minimize the damage caused by sulfates and calcium-based stabilizers such as double application of lime, use low calcium stabilizers (e.g. cement and fly ash), use non-calcium stabilizers, geosynthetic soil reinforcement, stabilization of the top with non-sulfate select fill, pretreatment with barium compounds, asphalt stabilization of the sulfate bearing soils and compacting to lower densities.

Organic contents in the soil are another consideration when selecting stabilization additives. Organic soil is a soil that would be classified as a clay or silt except that its liquid limit after oven drying (dry sample preparation) is less than 75% of its liquid limit before oven drying (wet sample preparation). Organic content can be determined in accordance to ASTM D-2974. If the organics content exceeds 1%, additional additive will need to be added to counter the cationic exchange capacity of the organic material.

Although chemical stabilization has proven successful in increasing the strength of the natural expansive soils by twenty to fifty times, and is widely used throughout Texas, situations arise where above mentioned approaches cannot be used. For example, chemical stabilization cannot be used when the temperature is below 40^{o}F and in cases there are not enough time for curing before traffic is routed back (Hopkins *et al.*, 2005)

Moisture Control

For some types of subgrade, the fluctuation in moisture content is quite detrimental. In those cases, the most effective remediation method is to control and minimize seasonal moisture variations.

One of the most important aspects of a successful road design is drainage. Rollings and Christie (2002) noticed that the lack of adequate surface drainage is one of the critical factors leading to problems with both collapsible and expansive subgrade soils. Some obvious drainage problem signs should be monitored such as water ponding in the drainage ditches, soft spots in the ditch, or the presence of plants and weeds that grow best in saturated or submerged environments. The new Mechanistic-Empirical (M-E) Design Guide (AASHTO, 2002) recommended improving surface drainage by lowering the ground water level, intercepting the lateral flow of subsurface water beneath the pavement structure, and removing the water that infiltrates the pavement's surface. To be more specific, special solutions should be considered when feasible. For instance, where climate is suitable, it may be possible to place a permeable layer over a swelling soil and limit or prevent drainage from it. Moisture buildup in this layer maintains the soil in a stable, saturated condition. Drainage ditches, sloped sections, water bars, cross-drains and inlet-outlet protections are recommended so that water does not accumulate in the median.

Vegetation transpiration may significantly decrease the moisture content of active soils and cause shrinking and deformation. Researchers reported that climatic extremes played a major role in causing and exacerbating damage to pavements and lightly-loaded structures, and that large vegetation often interacts with climatic extremes to heighten the problem (Ravina, 1984 and Snethen, 2001). Researchers believe that types and locations of trees should be considered in landscaping decisions, particularly involving soil having LL > 40 and PI > 25. Based upon the relative average rank analysis, the most influential trees are in the order of poplar, elm, oak, and ash. Experience and observations show that these types of trees should be planted at 1.6 to 3.3 ft (0.5 to 1.0 m) beyond the anticipated mature drip line or the anticipated mature height of the tree from pavements or pavements or building foundations (Snethen, 2001). Chen and Tian (1985) suggested using a lime trench between the structure and the tree to create a moisture transfer barrier. The depth of the trench should be 6.5 ft (2 m) and the lime fillings should be 4 to 8 in. (10 to 20 cm). The first "proximity rule" of distance to height of tree ratio (D:H) greater than one are widely used to avoid soil shrinkage settlement and damage to structures (Ward, 1953; Biddle, 1983 and 2001; Tucker and Poor, 1978) In New Zealand, Wesseldine (1982) indicated a threshold value of D:H of 0.75 for single trees to cause damage and 1.0 to 1.5 for groups of these trees.

Geosynthetics

The adoption of geosynthetic for pavement aims to improve long-term bearing capacity and performance of the road. There are eight types of geosynthetics: geotextiles, geogrids, geonets, geomembranes, geosynthetic clay liners, geopipe, geofoam, and geocomposites (Koerner, 2005). Geotextiles and geogrids are the most popular types of geosynthetics used in the road construction industry. Geotextiles are textiles consist of synthetic fibers rather than natural ones. These synthetic fibers have woven, non-woven, or knitted textile fabric. Geogrids are plastics formed into a very open, grid-like configuration. Geofoams are lightweight foam blocks that can be stacked and provide lightweight fill in numerous applications. Geocomposites consist of a combination of geotextiles, geogrids, and/or other geosynthetics in a factory-fabricated unit.

Geogrids have higher tensile strengths than geotextiles. Geogrids should be used on weak subgrades with CBR values less than 3 (Tutumluer and Kwan, 2005). Several researchers believe that the use of geogrids can effectively reduce the aggregate base thickness requirements when compared to the unreinforced section results. Geogrids with higher tensile strength and high aperture stability moduli were found to give overall higher geosynthetic stiffness and hence work better than geotextiles (Giroud and Han, 2004a, b). Stiff biaxial geogrids were first used for the reinforcement of pavement in 1982 at Canvey Island, near London, England to control reflective cracking and use of geogrids and geotextiles is becoming more common nowadays (Austin and Gilchrist, 1996).

The four major functions of geosynthetics used for pavements are: reinforcement, separation, filtration and drainage. Adding a geosynthetic layer can increase bearing capacity of a pavement structure by forcing the potential bearing capacity surface to develop along alternate, higher shear strength surfaces. The geosynthetic reinforcement can absorb additional shear stresses which would otherwise be applied to the problematic subgrade. If rutting occurs, geosynthetic reinforcement is distorted and thus tensioned. Due to its stiffness, the curved geosynthetic exerts an upward force supporting the wheel load and thus the lateral restraint and/or membrane tension effects may also contribute to load carrying capacity (Hufenus *et al.*, 2006).

Geosynthetics have been used successfully for many pavement projects. Their benefits include: extend service life, reinforce and inhibit reflection of cracks, facilitate compaction, improve bearing capacity, reduce necessary fill thickness, diminish deformations, delay rut formation, prevent water penetration to subgrade and reduce subgrade moisture susceptibility (Gurung, 2003; Hufenus *et al.*, 2006; Steward *et al.*, 1977).

The inclusion of geosynthetics in flexible pavement design is difficult since number of uncertainties arise when geosynthetics is applied under distress. The absence of an accepted design technique explains why this topic is still being researched despite the use of geosynthetics in pavement design and construction over many years ago. Following sections summarized methods and procedures identified in the literature search. These approaches shed some light on: (1) Where to place geosynthetics layer; (2) How to decide required thickness of aggregate; and (3) How to select appropriate geosynthetic type and appropriate strength to prevent pavement failure, or rutting, under traffic stresses.

The four main applications for geosynthetics in roads are overlay stress absorption, overlay reinforcement, base reinforcement, subgrade separation and stabilization. Based on their main targeted function, geosynthetics can be placed below or within the overlay, within base layer, near base-subgrade interface, or within subgrade layers. For low-volume roads, typically there will be an asphalt surface layer over an aggregate base layer. The combined surface and base layers act together to support and distribute traffic loading to the subgrade. However, weak clayey subgrades are often water sensitive and, when wet, may soften and deflect. Stresses will develop at the bottom of the granular layer, which will cause deep rutting and eventually, pavement cracking (Hopkins and Sharpe, 1985; Hopkins and Beckham, 2000). To lessen, or prevent, rutting of the aggregate layer during construction, or cracking due to base deflection after construction, geosynthetics may be placed at, or near, the bottom of the granular base, or on top of the finished subgrade (Figure 2.10). Use of geosynthetic reinforcement in such situation is gaining favor (Hufenus et al., 2006; Hopkins et al., 2005)

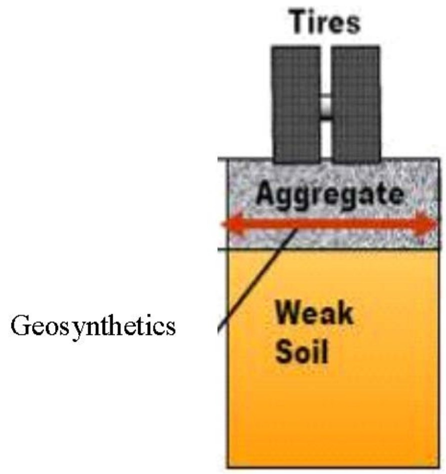


Figure 2.10 - Improving Pavement by Using Geosynthetics (from Hopkins et al.., 2005)

Table 2.3 gives an example of suggested appropriate geotextile for different survivability levels. Data are summarized by Cicoff and Sprague (1991) based on their test results of using lightweight geotextiles as permanent road stabilization.

Table 2.3 - Geotextile Specifications for construction Survivability in Low-Cost Low-Volume Roads (from Cicoff and Sprague, 1991)

Survivability Level	Subgrade Conditions	Base course Thickness*	Geotextile Mass/Area
Low	Dry, firm, flat	> 6" compacted	4 oz/sy
Moderate	Water sensitive, flat	> 3"-4" compacted	6 oz/sy
High	Water sensitive, grade>2%	> 3"-4" compacted	8 oz/sy

* For base course lifts less than 3", required survivability should be increased one level (i.e. low to moderate).

Use of geosynthetics inclusions in both wet and dry conditions increased tensile strength of the subsoil (Gurung, 2003, 1983; Abd El Halim *et al.*, 1985). The placement of a geotextile beneath an aggregate section increases the permissible stress on a subgrade by a factor of 1.64 to 2.0. (Steward *et al.*, 1977; Giroud and Noiray, 1981) Similar result is reported by Montanelli, *et al.* (1999) with an increased 1.5 to 2 structural layer coefficient of geogrid reinforced flexible pavement. The authors of the RACE design software (www.geotextile.com) therefore recommended using an average design improvement factor of 1.8. Kwon, *et al.* (2008) proved the technical response benefit of using geogrids in pavement base course reinforcement based on a full-scale test study. Much lower subgrade vertical deformations and base course vertical and horizontal deformations were measured in the geogrid reinforced section when compared to the deformations recorded for the unreinforced control section. Cicoff and Sprague (1991) concluded that geosynthetics may or may not enhance initial pavement performance, but will likely enhance future pavement performance. However, the benefit data could not be utilized for section to section comparisons, measured values of stress, strain and deflection are highly case specific.

MATRIX OF SOLUTIONS

The results from the maintenance and rehabilitation methods for flexible pavements search are listed in Figure 2.11. The information is resourced from the documentation summarized literature review. The diagram provides a link between probable distresses, their sources and the appropriate remediation. It divides the different distresses by the structural member or layer that is failing. The different rehabilitation methods to repair flexible pavement are listed and divided into subcategories depending on what type of distresses they might be suitable to repair. This figure is being developed into a matrix that will be incorporated into TXDOT remediation strategies. The matrix will also be expanded to include the items enumerated in the proposal such as:

- *Under what traffic volume, environmental condition, pavement structure the solution is effective?*
- *Which alternative is appropriate for maintenance, rehabilitation or reconstruction?*
- *What are the advantages and disadvantages of each solution?*
- *What is the cost-benefit of the solution?*
- *How adaptable the solution is to TxDOT operation?*

Layers	Distresses	Maintenance & Rehabilitation Methods
Asphalt	**Surface Rutting** **Instability Rutting** **Shoving** **Fatigue Cracking**	**Micro surfacing** **Fog Seal** **Crack Seal** **Sand Seal** **Slurry Seal** **Ultra-Thin Wearing Course** **Chip Seals** **Hot in Place** **Cold in Place** **PCC Overlay (Thick)** **Ultra-Thin Whitetopping** **Hot Mix Overlay**
Base	**Structural Rutting** **Shrinkage Cracking**	**Full Depth Reclamation** **Roller Compacted Concrete (Base)** **Stabilization**
Subgrade	**Moisture Intrusion** **Structural Rutting** **Shrinkage Cracking**	**Stabilization**

Figure 2.11 - Probable Appropriate Remediation for Different Layers

COST ANALYSIS

Cost analysis is a technique for the evaluation of multiple alternatives and identification of the lowest cost alternative using financial principles. Three basic types of cost analysis evaluation were described by Sewell and Marczak (1997): cost allocation, cost-effectiveness analysis, and cost-benefit analysis. Cost allocation is the simplest of the three methods, since it consists of setting up budgeting and accounting systems in a way that will let program managers determine a unit cost.

Unit costs for road construction are usually estimated based on historic experience, either by constructed costs or historical bids. To estimate the unit price by constructed cost, it is necessary to consider the production rates, labor and equipment costs, profits and risks, taxes, and material costs. The R.S. Means Construction Cost Guides are commercially available to obtain approximate unit prices. To calculate unit costs by historic bid, it is necessary to average the bids submitted by contractors over a certain period. The costs may be adjusted to the time of construction.

Cost-effectiveness analysis assumes that a certain benefit or outcome is desired, and that several alternative ways exist to achieve it. The basic question asked is "which of these alternatives is the cheapest or most efficient way to get this benefit?" By definition, cost-effectiveness analysis is comparative, while cost-benefit analysis usually considers only one program at a time. Another important difference is that while cost-benefit analysis always compares the monetary costs and benefits of a program, cost-effectiveness studies often compare programs on the basis of some other common scale for measuring outcomes (Sewell and Marczak, 1997).

The cost benefit analysis is intended to verify if the economic benefits of the project compensate for the economic costs. The two important tools to demonstrate the benefit of a project are benefit-to-cost-ratio and net rate of return. The benefit-to-cost ratio is the total monetary value of the benefits divided by the total monetary value of the costs. The net rate of return is just basically the total costs minus the total monetary value of the benefits. The idea behind cost-benefit analysis is simple: if all inputs and outcomes of a proposed alternative can be reduced to a common unit of impact (namely dollars), they can be aggregated and compared (Sewell and Marczak, 1997).

Life-Cycle Cost Analysis

Life-Cycle Cost Analysis (LCCA) is defined by the Federal Highway Administration (FHWA) as an analytical tool that provides a cost comparison between two or more competing design alternatives that provide equivalent benefits for the project being analyzed. The typical LCCA for pavement system includes costs for initial design and construction, operation and maintenance, rehabilitation and salvage.

In 2002 the FHWA published a "Life-Cycle Cost Analysis Primer" which provided the LCCA methodology for the evaluation of alternative infrastructure investment options. The first step is to establish the alternatives that will accomplish the structural and performance objectives of the project. The activity timing has to be determined for the initial and future activities involving each project design alternative. All the related costs for construction and maintenance throughout the analysis period for each alternative have to be included in the analysis, as well as the effects of the construction and maintenance activities on users. With the predicted schedule of activities all the costs during the analysis period are converted into present dollars by using a technique known as "discounting", and are finally all added up for each alternative. The equations used to calculate the present value or discounting are the following:

$$Present\ Value = Future\ Value \times \left(\frac{1}{(1+r)^n} \right) \tag{2.1}$$

$$Total\ Present\ Value = Initial\ Cost + \sum Future\ Value \times \left(\frac{1}{(1+r)^n} \right) \tag{2.2}$$

where:
r = real discount rate
n = number of years in the future when the cost will be incurred

The lowest of the cost summations of each alternative can be determined as the most cost-effective alternative.

CHAPTER 3 - UNDERSTANDING AND DOCUMENTING EXTENT OF PROBLEM AND SOLUTIONS IN TEXAS

This chapter consists of the work performed to understand and document the extent of the problem and solutions as related to intersections in Texas. The Aside from the literature review, surveys and district interviews were carried out and are summarized in this chapter.

SURVEYING TXDOT DISTRICTS

A first set of questionnaire was developed and distributed to all districts. The questionnaire, which was concise to minimize the demand on the time of the TxDOT staff, was an initial step that served the following purpose (see Appendix A):

- To document the extent of the excessive permanent deformation at their intersections,
- To locate the districts that perceive that they can benefit from the outcome of this study,
- To identify the current solutions typically used to remedy this problem,
- To document the perceived performance of their intersections after remediation, and
- To solicit projects that can be incorporated in this study.

To best present the summary of this questionnaire, the results to each question is documented sequentially.

Question 1: Do your pavements experience distress at the intersections of low volume roads?
There were a total of 17 responses to the survey as summarized in Figure 3.1. Out of the 17 responses 16 stated that the districts they represented experience distress at intersections of low volume roads and one response stated that no distress problems existed at intersections (see Figure 3.1a). Figure 3.1b shows that the 16 responses are from 12 Districts. Therefore in total, 12 Districts documented distress problems, one no distress.

Question 2: If yes, what percentage of the intersections experiences any type of distress?
The detail of the districts that exhibit distress at intersections based on the responses is listed in Figure 3.2. The figure not only shows the responses from the districts but the percentage of intersections experiencing any type of distress based on the responses. As depicted in the figure, both Fort Worth and Lubbock had three responses. Tyler District does not seem to experience distress problems at intersections. A line on the 25% limit of distress at intersections was arbitrarily selected to distinguish those districts that have a larger percentage of its pavements exhibiting distress versus Districts that have low number of its pavements intersections with distress. Based on that limit, San Antonio, Lubbock, Houston and Fort Worth are Districts that

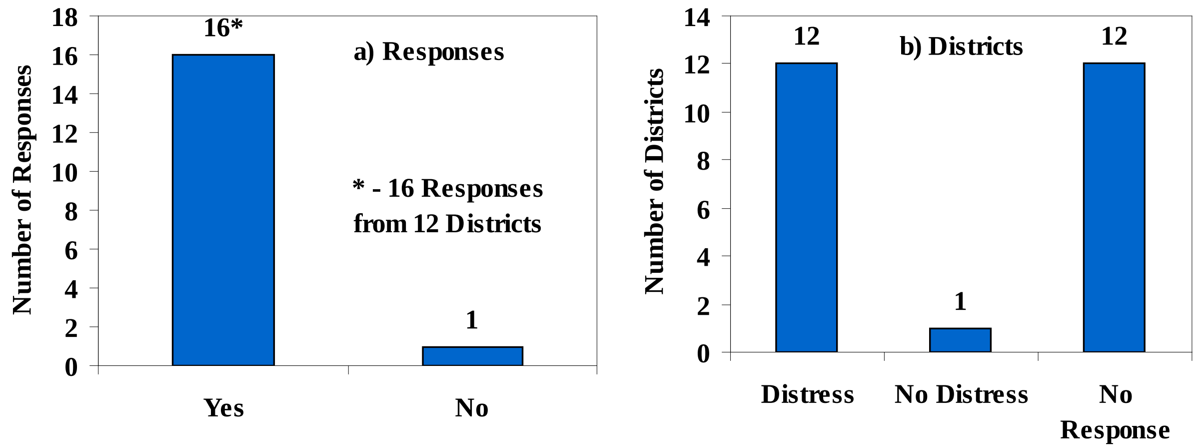


Figure 3.1 – Results of Survey Responses to Districts Experiencing Distress at the Intersections of Low Volume Roads

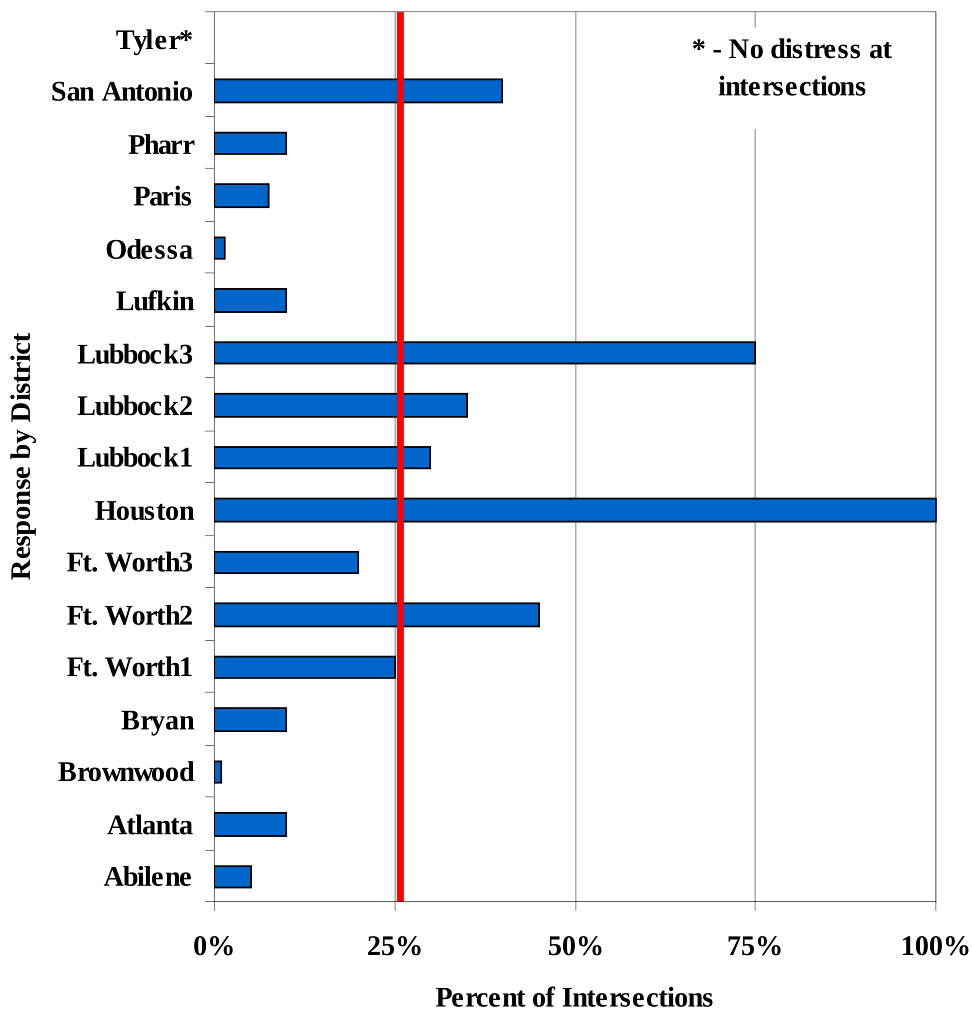


Figure 3.2 - Percent of Intersections Experiencing Distress in the Districts

can benefit highly from the outcome of this research showing higher number of intersections that demonstrate distress. On the other hand, the remaining eight districts show low numbers of intersections with distress. It could be of benefit to this project to document and learn what factors contribute to minimize distress at intersections.

As demonstrated in Figure 3.3, the districts with responses represent a good regional distribution of the state. The research effort will be focused the states highlighted in the Figure 3.3.

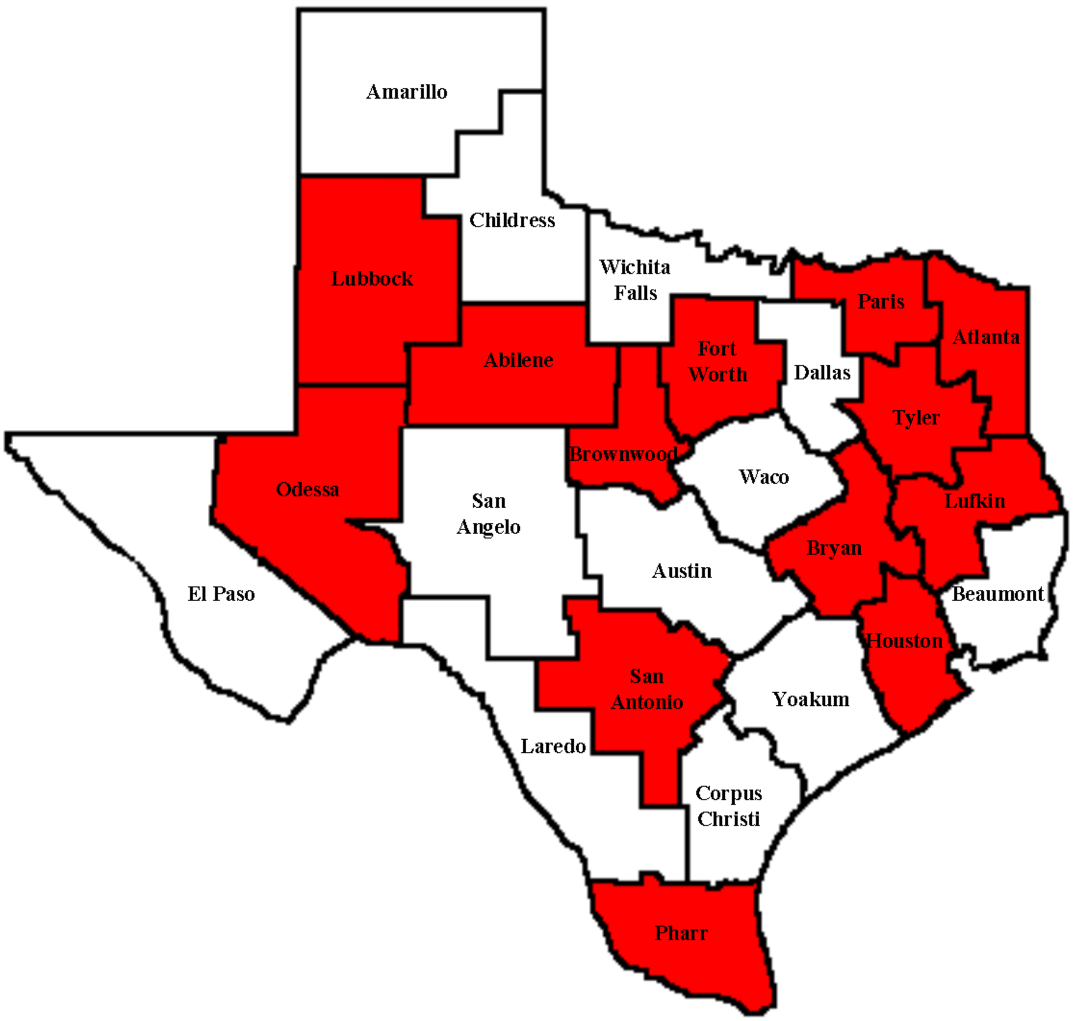


Figure 3.3 – Distribution of Districts that Responded to Survey

Question 3: Approximately what percentages of distressed intersections experience the following distress severity? Low Severity (___%) Medium Severity (____%) High Severity (___%)
Figure 3.4 summarizes the level of severity for each district based on their responses. As with Figure 3.3, the 25% limit is highlighted as an arbitrary marker to distinguish, in this case, the level of severity in the districts. All the districts show at least a low level of severity. Districts with medium to high level of severity include San Antonio, Paris, Lufkin, Lubbock, Houston, Fort Worth, Atlanta, and Abilene.

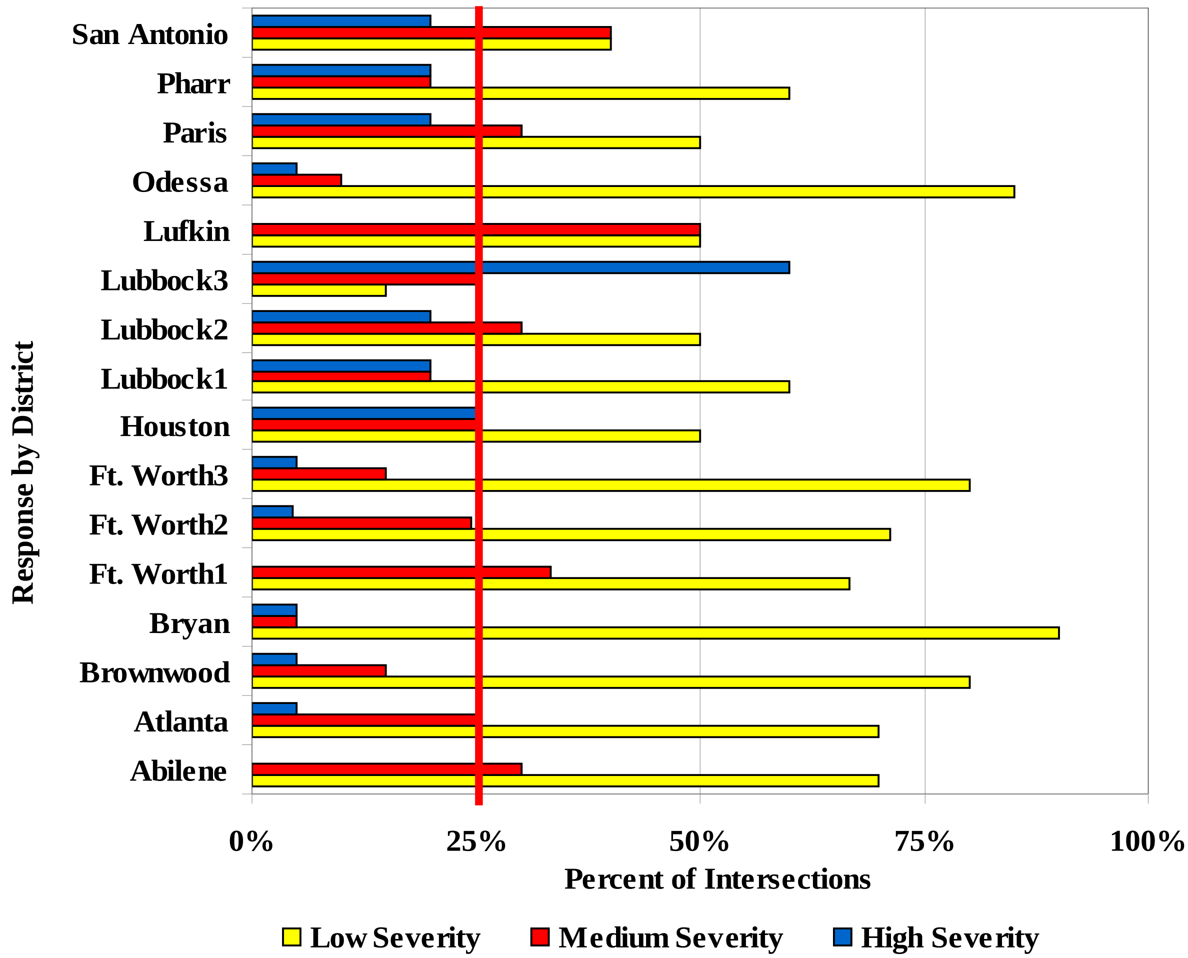


Figure 3.4 - Level of Distress at Intersections

Question 4: What distress types are common at your intersections on low volume roads?
Figure 3.5 shows that at least 75% of responses selected all four distresses. In addition, other distresses documented were loss of aggregate, pot holes, rolling of seal coat, rub-board effect, and edge break off.

<u>*Question 5-9 referred to the all five distresses listed in Question 4.*</u>
A sample of the question related to rutting is provided as an example.

(5) If ***rutting*** is an issue at intersections, please select: (*check all that apply*)
a) Probable cause:

? Inadequate structures - specify (ex. weak subgrade)____________________

? Construction quality - please specify (ex. site preparation)____________________

? Traffic - please specify (ex volume, slow moving, channeled)____________________

? Environmental condition - please specify (ex. moisture, temperature)____________________

? Inadequate drainage____________________

? Subgrade type - please specify (ex. clayey, sandy)____________________

? Other____________________

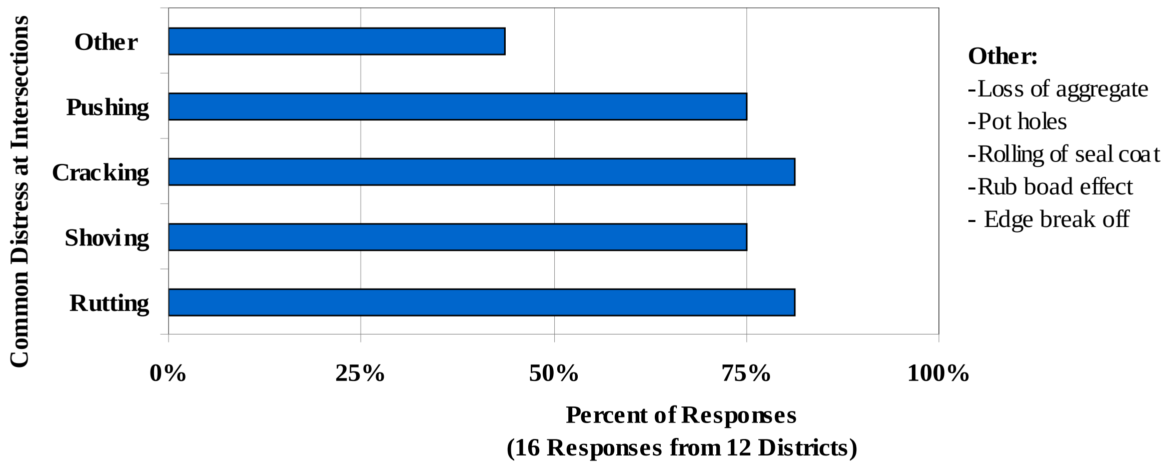
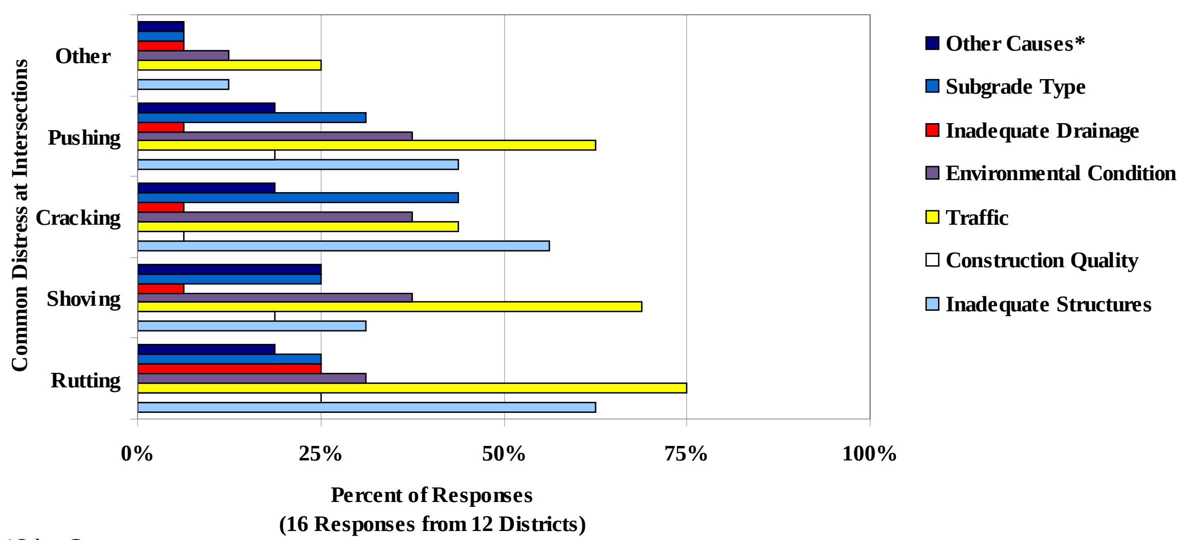


Figure 3.5 - Type of Distress at Intersections

The results from questions 5 through 9 are presented in five tables in Appendix B and are summarized in Figure 3.6. The most prevalent causes for all distresses seem to be subgrade type, environmental conditions, traffic, and inadequate structure. Also indicated in the figure are the other causes for each of the common distresses.



*Other Causes:

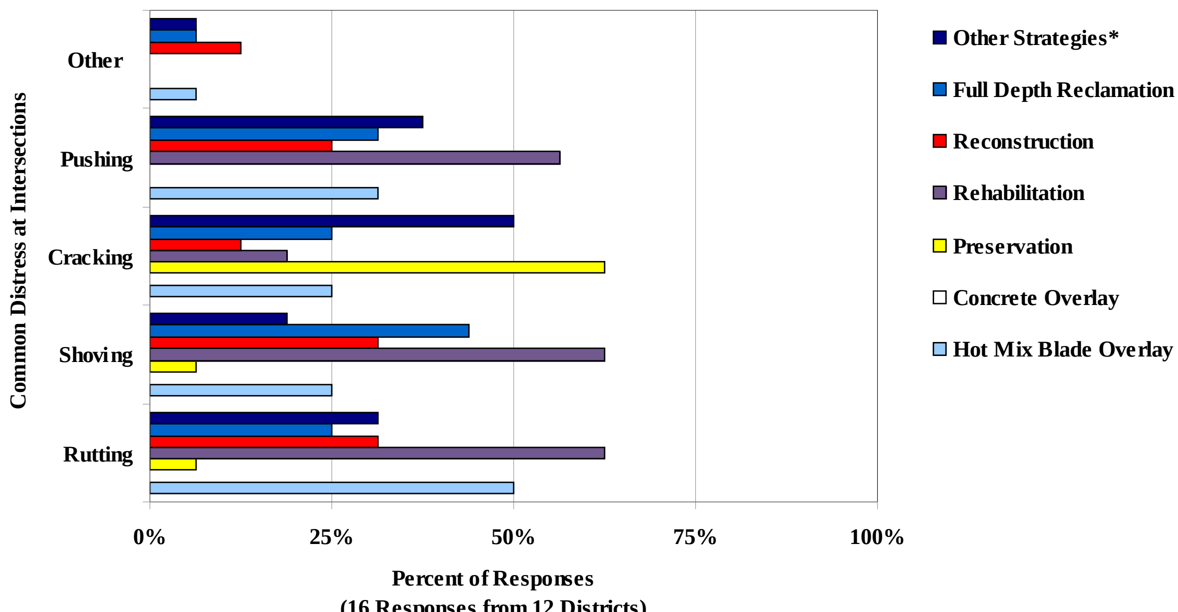
- Rutting : Hot mix, Utilities,
- Shoving : Too much asphalt, Width of roadway and un-uniform subgrade (loam and sand not mixed properly),
- Cracking: Age of roadway,
- Pushing : Lack of vegatation on edge of pav., removal of 6-12 in. of pav. struc. on edge of roadway, and roadway elevation,
- Other: Edge break off /Pot holes-Age of roadway, snow removal

Figure 3.6 – Causes of Distress for Each Type of Distress

<u>Question 10: Please fill the table below regarding solutions you typically use to remedy each distress and provide typical performance life of each remedy.</u>

The results show that rutting, shoving and pushing are remediated similarly and mainly by means of full-depth reclamation (FDR), reconstruction, rehabilitation, and hot mix overlay (see Figure 3.7). Cracking on the other hand is handled mainly by pavement preservation. Appendix B includes tables that summarize these strategies selected by each of the districts. A number of respondents selected other as a means of remediation than the ones listed in the survey. For each distress, these strategies are also listed in Figure 3.7.

The typical performance life of each remedy is presented in Figure 3.8. For all strategies listed the performance period is either 1-3 years or 3-10 years. In several of these strategies, the responses were mixed showing in some instance the remediation could be either of the two performance periods. That shows some strategies could last anywhere between one to ten years.



Other Stratigies*
- Rutting : Rut fill & seal, spot base repair, blade level-up with maintainer, shaving cold mix overlay
- Shoving : Spot base repair, mill & blade level-up with maintainer, shaving and cold mix overlay
- Cracking : Crack seal, spot base repair, spot seal, crack pouring, fog seal, overlay, seal coat, scrub seal
- Pushing : Spot base repair, mill & blade level-up with maintainer, widing, shaving and cold mix overlay, good e dge vegitation
- Other: Edge break off: Fog seal, chip seal, good edge vegitation, blade edge with no vegitation

Figure 3.7 – Remediation Strategies for Distresses at Intersections

The results from the questionnaire were a good first step to understanding and document the sources and problems at intersections. The results provide insight on several areas where more investigation were needed and should be targeted. To further investigate issues at intersections in the districts and to help gather more information that can be used in this research study, eight districts were visited. Several personnel from each district were interviewed. In the interview process, two information-gathering tools were utilized. A detailed questionnaire was presented to the panel first. Personnel from each district were then interviewed for close to two hours in an informal group setting to take advantage of their expertise. This provided very valuable insight and allowed for an additional source of input from the agency. The questionnaire that was submitted to the districts is provided in Appendix C. The results of the questionnaire are summarized in Appendix D. In addition, the summary of the interview for each of the participating district is provided in Appendix E. The feedback from the districts was very valuable and not only provided a good foundation as far as the treatment needs and common distresses at intersections, but the mechanisms and decisions utilized by the districts based on the funding limitations. In most districts, rural road are listed of the lowest priority and maintenance crews are usually the force that is used to extend the life of those pavements.

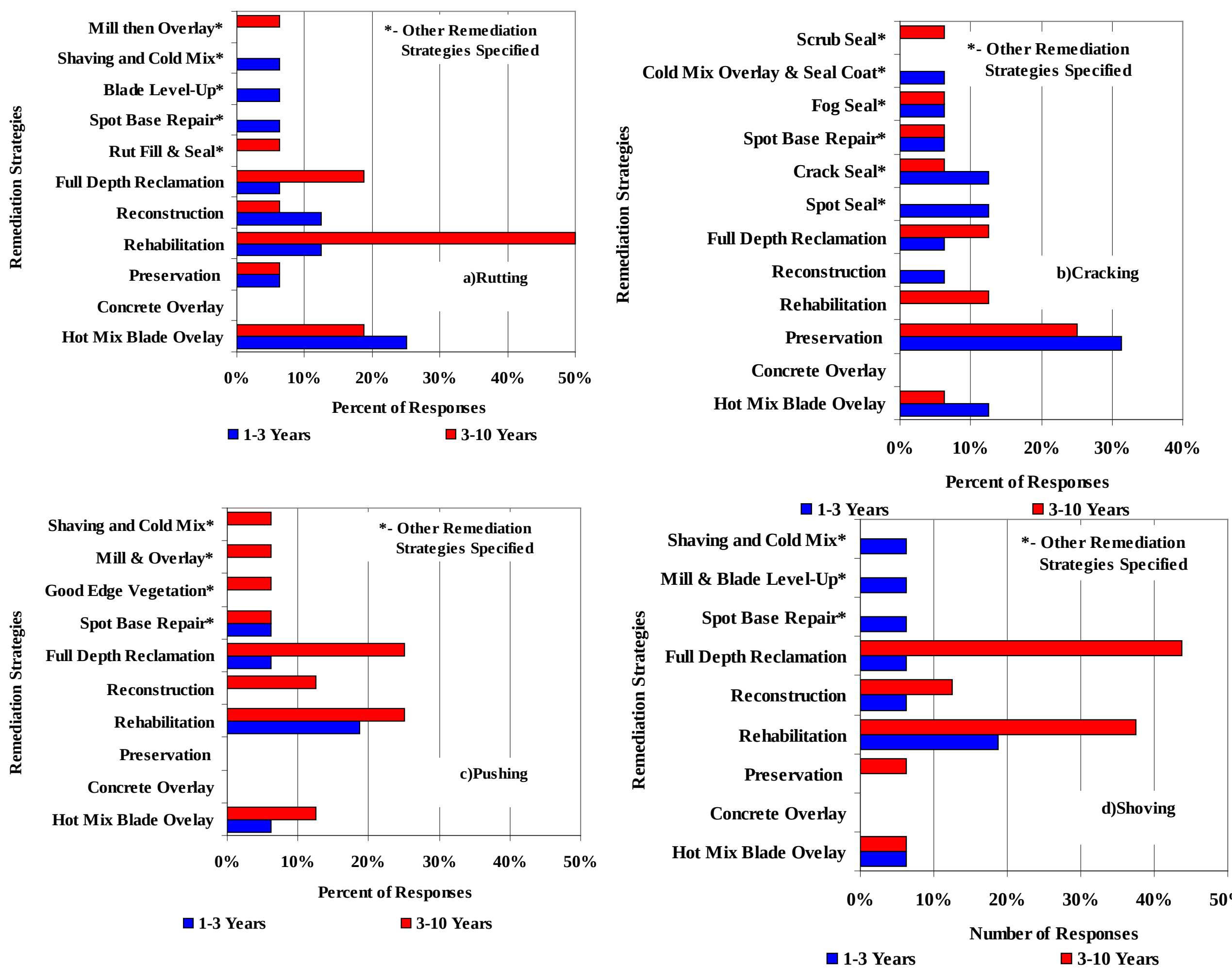


Figure 3.8 – Typical Performance Period for Selected Remediation Strategies

CHAPTER 4 - METHODOLOGY

Since the sources of excessive distress of intersection and the possible solutions are diverse, the development of an expert system seems logical. The expert system was developed to incorporate the knowledge gained from the literature review, district surveys and interviewing district personnel. The best support for utilizing an expert system was described by a TxDOT employee.

> *As far as the product coming out of this project, we don't have a problem with an expert system. We are getting a lot of inexperienced people with the new generation of engineers and most of the time, they go out there and see some cracking and decide to overlay. They do not know if it's a base failure or not. They're not looking any further then what they see on the surface and that becomes a big issue. But give someone a tool like the expert system, where they can go in and give them an idea of what to look at, and then you start asking questions. That is where I see the utility or advantage of this tool.*
>
> *We have had several experiences out there where we get calls saying that the pavement shows spalling and we tell them what to do. A year later, they call back and say that we told them wrong. So we finally said, well, you need to send us pictures first, what they were classifying as spalling was probably not spalling. It actually needed to be a full-depth repair. They don't know what cracking is, they don't know, unless you show them. They do not know the different type of rutting that can be out there.*
>
> *So if you have a tool that say you need to open it up and compare it to a picture of it then have a flowchart on what you do with this distress. We can minimize misdiagnosing the problem and get more life out of our pavement. Therefore, the guideline is also very useful as well, especially for field work.*

This expert system can be utilized as an advisory tool to users allowing them to better identifying the predominant distress and recommends alternative remediation strategies either maintenance and or rehabilitation. The information summarized next is a sample of what was incorporated into the development of the expert system:

1. Typical distresses found on Texas intersections
    a. Description of each distress type (with representative photos)
    b. Most probable causes of each type of distress

    c. Layer(s) of pavement structure most probably contributing to distress

2. Typical remediation strategies (Maintenance and Rehabilitation)

    a. Description of each remediation process
    b. Probable feasibility of each remediation strategy to solve each type of distress identified in Item 1
    c. A matrix of effectiveness vs. cost for each feasible solution including cost-benefit ratio considering traffic volume and budgetary constraints

3. Information for determining best remediation strategies

    a. Volume of traffic
    b. Depth, extent and shape of the rutted section
    c. Coring and sampling
    d. Nondestructive testing with FWD and/or GPR
    e. Life-cycle cost analysis

4. Best construction practices for each remediation method.

An expert system is a knowledge-based system whose performance is intended to rival that of human experts while being highly domain specific. It can be used to record and distribute scarce expert knowledge, to apply the expert knowledge to remote locations, to ensure the quality of problem solving, and to train experts out of ordinary people. Even though a decision tree approach can be utilized for arriving to the most appropriate solutions, its implementation can be rather complex especially when more variables are introduced.

The expert system has a knowledge base that includes all the factors that allows engineers and users to reach the final decision. Intermediate and final conclusions are available with comments and an explanation of how those conclusions were reached. The expert system in this case will serve as a step-by-step advisory tool for determining the optimum solution. Traditionally, a guideline with look up tables are used to develop or carryout the decision making. However, utilizing the expert system facilitates the process and provides a means for future modification and explanation of the knowledge base. The modularity of the database structure in an expert system allows for including additional options that are proven successful with time. This also applies to incorporating knowledge of pavement engineers as it becomes available. The expertise of the engineers that are experienced with intersection remediation would be utilized by everyone. In addition to its modularity and its database interaction, an expert system has the ability to communicate with executable programs and with database if that process becomes desirable at a future date. Also, even though this is outside the scope of this project, an expert system has the flexibility to incorporate mathematical and analytical models, and mechanistic-empirical relationships. The expert system ensures a more rational, faster and consistent manner of selecting an alternative. This translates into uniformity in the decision process that would promote more consistency across the districts.

FRAMEWORK OF THE EXPERT SYSTEM

Figure 4.1 illustrates the typical building blocks of an expert system which include: inference engine, knowledge base, explanation subsystem, and a user interface subsystem. In general, users supplies facts or other information to the expert system and obtain expertise in response by accessing the knowledge base through the system's user interface via the inference engine. In this case, users provide the most predominant distress and AADT and in return access these decisions "knowledge base" to provide users with the best expertise. Internally, the expert system consists of three main components. The knowledge base contains the knowledge with which the inference engine draws conclusions. These conclusions are the expert system's responses to users' queries for expertise. The explanation block is one of the most attractive attributes of an expert system. Since the system remembers its logical chain of reasoning, users may ask for an explanation of a recommendation and the system will display the factors it considered in providing a particular recommendation. This attribute enhances users' confidence in the recommendation and acceptance of the expert system.

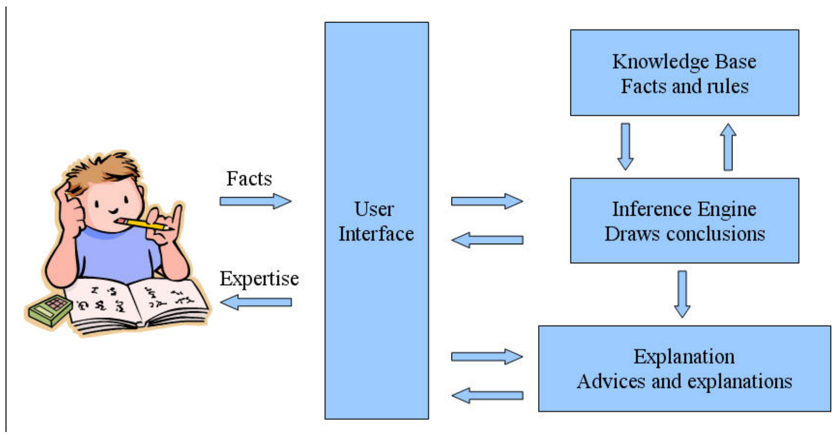


Figure 4.1 - Typical Expert System Components

This advisory tool consists of four main components: Input Data, Predominant Distress, Remediation Alternatives, and LCCA. Figure 4.2 illustrates the overall conceptual design of the system. The Input Data, input provided by users, includes the project information, traffic data, distress survey, and nondestructive testing data. The Predominant Distress component is the section of the program where the predominant distress is identified based on users experience or determined using the expert system based on the Input Data component. The Remediation Alternatives and LCCA components are the output or end products of the expert system. The Remediation component provides the list of best remediation strategies. These remediation strategies are presented as maintenance and rehabilitation alternatives. For each alternative, a LCCA is performed and presented as a prospect to improve the pavement condition at intersections. The next sections describe the main components of the expert system.

Input Data

The Input Data component contains two types of input: a) trivial and b) essential. The trivial input is the project information data such as the project name, county, district, intersection location, CSJ user name and date. This information is only used for identification and does not

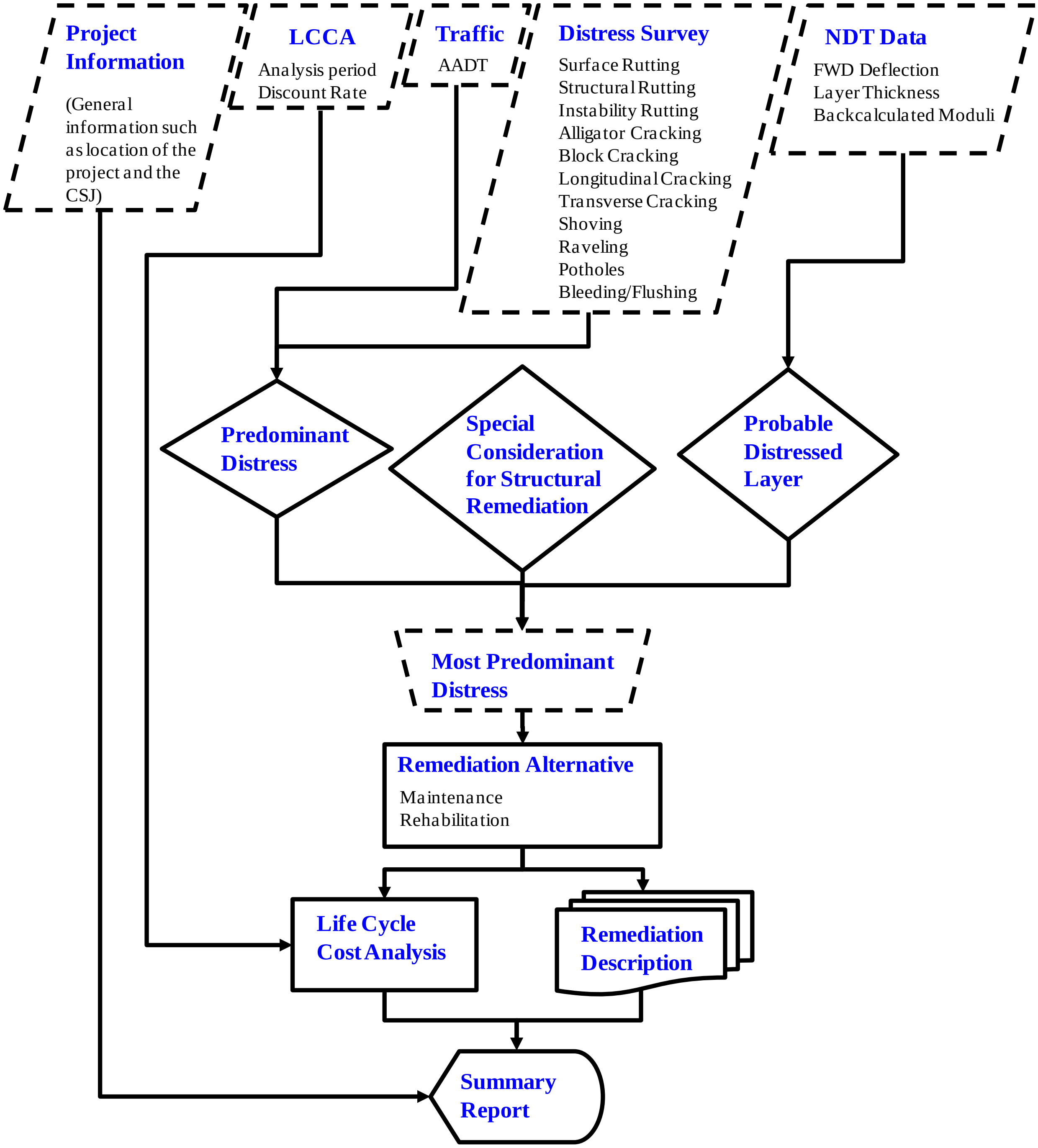


Figure 4.2 - Overall Schematic of the Guideline Tool for Selecting Alternative Remediation Strategies for Flexible Pavements at Intersections.

impact the decision used in the expert system. The second category of input, which is essential to the decision process, is divided into the following four sections:

1. Traffic, more specifically annual average daily traffic (AADT)
2. LCCA information, mainly the analysis period and discount rate to determine the "Total Present Value (TPV)" for all selected remediation strategies.
3. Distress survey and
4. NDT data.

Distress Survey
The program includes a module that allows users to incorporate the results of a distress survey at intersections. The length and area of each distress in combination with the level of severity are required input for each distress. Table 4.1 presents the common distresses at intersections followed with the measures of identifying the level of distress and how to specifically to measure the distress at intersections. The expert system provides detailed description for each distress that includes schematics and photos. Figure 4.3 includes sample photos that can be used for identifying the severity level. The distresses identified as crucial were: Surface Rutting, Structural Rutting, Instability Rutting, Alligator Cracking, Block Cracking, Longitudinal Cracking, Transverse Cracking, Shoving, Raveling, Potholes, and Flushing/Bleeding.

The identified types and extents of distressed area are used to determine the predominant distresses. In addition to providing the severity level and the process of measuring the distress, the expert system provides detailed description for each distress that includes schematics and photos. An example of the detail for one distress is provided in Figure 4.4.

NDT Data
The NDT data used to in the expert system are: the FWD deflections, layer thicknesses, and backcalculated layer moduli. The three sets of information are also utilized by the system to identify potential weak layers. Tables 4.2 to 4.5 present the information used in the expert system to identify if there is a potential structure weakness in the pavement layers. These rules are triggered if the users provide NDT data, layer thickness, and/or layer moduli as input.

Predominant Distress

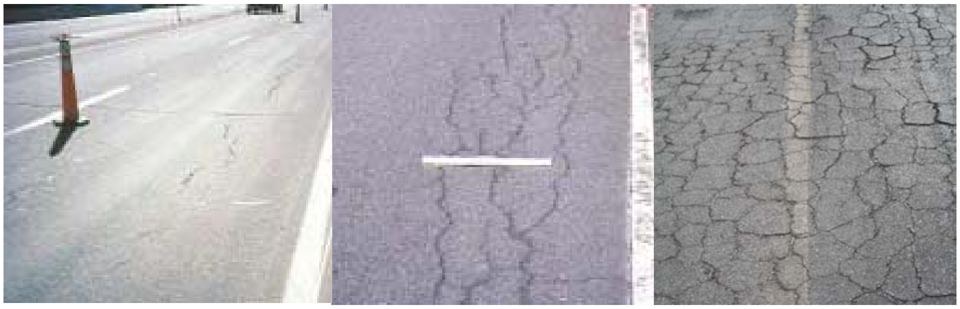
The user can accept the advice from the expert system on the predominant distress based on the distress survey and NDT data provided or use her/his own experience to select or override the decision provided by the expert system.

In decision science, our specific problem falls under multi-attribute decision making (MADM) since the alternatives are predetermined. This method is particularly attractive for making preference decisions (e.g., evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes (Dashti et al., 2010). Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is an example of MADM. The principle behind TOPSIS is simple. The chosen alternative should be as close to the ideal solution and as far from the negative-ideal solution as possible (Dashti et al., 2010). The ideal

Table 4.1 - Summary of Distresses Utilized in Condition Survey at Intersections

Distress	Severity	Measure of Distress
Surface/ Wear Rutting Structural Rutting Instability Rutting	Low severity is measured less than 0.5 in., Medium severity is measured greater than or equal to 0.5 in. and less than 1 in. and High severity is measured greater than or equal to 1in.	Rutting is measured as a length in feet of the section's total wheelpath area that is rutted. Add rutted area together for each wheel path.
Alligator Cracking	Refer to photos*	Alligator cracking is measured based on the area of distress in square feet
Block Cracking	Low severity is measured less than 0.5 in., Medium severity is measured greater than or equal to 0.5 in. and less than 1 in. and High severity is measured greater than or equal to 1in.	Block cracking is measured based on the area of distress in square feet
Longitudinal Cracking		Longitudinal cracking is measured as a length in feet of the section's total distressed area.
Transverse Cracking		Transverse cracking is measured as the number of cracks of the section's total distressed area.
Shoving	Based on engineering judgment	Shoving is only measured as low, medium or high
Raveling	Low severity when percent of the rated surface area less than or equal to 15% is raveling, Medium severity when percent of the rated surface area less than or equal to 50% but greater than 10% is raveling, and High severity when percent of the rated surface area greater than 50% is raveling.	Raveling is measured based on the area of distress in square feet
Potholes	Low severity is measured less than 0.5 1 pothole, Medium severity is measured greater than or equal to 1 and less than 2 potholes and High severity is measured greater than 2 potholes	Potholes are measured as the number of potholes of the section's total distressed area.
Bleeding / Flushing	Low severity when percent of the rated surface area less than or equal to 15% is raveling, Medium severity when percent of the rated surface area less than or equal to 50% but greater than 10% is raveling, and High severity when percent of the rated surface area greater than 50% is raveling.	Flushing is measured based on the area of distress in square feet

*** - Figure 4.3 present the photos used to identify the severity level at intersections for alligator cracking.**



<u>Low Severity</u>: Few connecting cracks with no spalling; cracks are not sealed.

<u>Medium Severity</u>: Cracks forming alligator pattern; slightly spalled; cracks maybe sealed.

<u>High Severity</u>: Cracks forming alligator pattern very wide spread; pieces are loose cracks maybe sealed; moderate to severe spalling

Figure 4.3 – Severity Level Identification for Alligator Cracking

Description: **Wear rutting, which is due to progressive loss of coated aggregate particles from the pavement surface and which is caused by combined environmental and traffic influences (the rate at which wear rutting develops may be accelerated when winter ice control abrasives accumulate).**

Mechanism: **Excessive vertical compressive stresses on the HMA surface causing non-recoverable permanent deformation in the asphalt layer of a pavement structure. Surface rutting will be classified to three levels of severity: a) Low severity is measured less than 0.5 in., b) Medium severity is measured greater than or equal to 0.5 in. and less than 1 in. and c) High severity is measured greater than or equal to 1in.**

Causes:

- **Studded tires/chain action**
- **Compaction (density): Insufficient compaction of HMA layers during construction. If it is not compacted enough initially, HMA pavement may continue to densify under traffic loads.**
- **Raveling**
- **Traffic loading densification**

Prevention: **The use of quality design, quality aggregate and quality liquid asphalt; durable hot-mix asphalt surface course with sufficient asphalt cement content; Proper compaction during construction; Adequate drainage.**

Figure 4.4 – Sample of the Description Pavement Distress

Table 4.2 - Index Parameters Based on FWD to Diagnose Possible Distressed Layer

w7	SCI	Diagnosis
<= 1.2	<=20	Good Base, Stiff Subgrade
	>20,<40	Marginal Base, Stiff Subgrade
	>=40	Thin or soft base, Stiff Subgrade
1.3-1.9	<=20	Good Base, Marginal Subgrade
	>20,<40	Marginal Base, Marginal Subgrade
	>=40	Thin or Soft Base, Marginal Subgrade
>=2.0	<=20	Good Base, Soft or Wet Subgrade
	>20,<40	Marginal Base, Soft or Wet Subgrade
	>=40	Thin or Soft Base, Soft or Wet Subgrade

Table 4.3 – Subgrade Modulus Ranges Used to Diagnose Quality of Subgrade Layer

Subgrade Modulus, ksi	Diagnosis
Less than 4	Very Poor
4-8	Poor
8-12	Fair
12-16	Good
>16	Very Good

Table 4.4 – Ratio of Base to Subgrade Modulus Used to Diagnose Quality of Base Layer

Ratio (Ebase/Esubgrade)	Diagnosis
>3	Good Base
2-3	Marginal Base
<2	Poor Base

Table 4.5 - Index Parameters Based on FWD and Layer Thickness to Diagnose Possible Distressed Layer

Index Parameters	Asphalt Thickness, in.				Diagnosis
	>5	<=5,>=2.5	<2.5,>=1	<1	
SCI	<4	<6	<12	<16	Very Good Asphalt Layer
	4-6	6-10	12-18	16-24	Good Asphalt Layer
	6-8	10-15	18-24	24-32	Fair Asphalt Layer
	8-10	15-20	24-30	32-40	Poor Asphalt Layer
	>10	>20	>30	>40	Very Poor Asphalt Layer
BCI	<2	<3	<4	<8	Very Good Base Layer
	2-3	3-5	4-8	8-12	Good Base Layer
	3-4	5-9	8-12	12-16	Fair Base Layer
	4-5	8-10	12-16	16-20	Poor Base Layer
	>5	>10	>16	>20	Very Poor Base Layer
w7	<1	<1	<1	<1	Very Good Subgrade Layer
	1-1.4	1-1.4	1-1.4	1-1.4	Good Subgrade Layer
	>1.4-1.8	>1.4-1.8	>1.4-1.8	>1.4-1.8	Fair Subgrade Layer
	>1.8-2.2	>1.8-2.2	>1.8-2.2	>1.8-2.2	Poor Subgrade Layer
	>2.2	>2.2	>2.2	>2.2	Very Poor Subgrade Layer

solution is formed as a composite of the best performance values exhibited (in the decision matrix) by any alternative for each attribute. The negative-ideal solution is the composite of the worst performance values. This method considers three types of attributes or criteria: a) qualitative benefits, b) quantitative benefits, and c) cost. The detailed algorithm used in for selecting the predominant distress using TOPSIS process is included in Appendix F.

Remediation Alternatives

The remediation alternatives are categorized into maintenance and rehabilitation. The maintenance group, which includes temporary strategies that are short term fixes, include: chip seal, crack seal, fog seal, microsurfacing, sand seal, slurry seal and ultrathin wearing course. On the other hand the rehabilitation strategies, longer term fixes include: cold in-place recycling, hot in-place recycling, hot mix overlay, hot mix with either reclaimed asphalt pavement or recycled asphalt shingles, PCC overlay, whitetopping, full depth reclamation, roller compacted concrete, and stabilization.

These remediation strategies were selected based on literature review, and Texas district inputs. The tables in Appendix D summarize the suitability of remediation alternatives to distress from several state and national agencies and the districts. Figure 4.5 contains one of the summary tables that were compiled from the literature review during the early stages of this research study. The table provides the appropriateness of most common distress with remediation alternatives. In most cases, where appropriate, the distress is separated into three levels: low, moderate, and high. The symbols in the table linked the appropriateness of the remediation to each distress level. A solid circle indicated that the remediation is appropriate, a circle with a dot indicated that the remediation maybe appropriate, an empty circle suggested that the remediation is not appropriate, and finally a cross symbol indicated that the remediation is not a candidate or no information was found for that case. The expert system incorporates the recommendations between the distress and remediation from all groups.

Figure 4.6 shows the relationships used between the distresses and appropriate remediation strategies from all sources. The color in each cell is illustrative of the appropreiateness of the methods. A green cell indicated that the remediation is appropriate, a yellow cell indicated that the remediation maybe appropriate, an orange cell suggested that the remediation is not appropriate, and finally a red cell indicated that the remediation is not a candidate or no information was found for that case. The frequency bars relate the consensus of the agencies or in this case the experts. The higher the frequency bars, the stronger the consensus is between the experts. This matrix can be modified and refined as more knowledge is fed into the system.

Summary Matrix from Literature Review and Texas District Recommendations		Maintenance							Rehabilitation									
		Chip Seals	Crack Seal	Fog Seal	MicroS.	Sand Seal	Slurry Seal	UTWC	Cold In-Place	Hot In-Place	Hot Mix Overlay	RAP	RAS	PCC Overlay	UTWT	FDR	RCC	Stab.
Surface Rutting	Low	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	×	×
	Moderate	⦿	⦿	●	⦿	⦿	⦿	⦿	⦿	⦿	●	●	⦿	●	×	●	×	×
	High	○	○	○	○	○	○	○	⦿	⦿	⦿	⦿	⦿	●	×	●	×	×
Structural Rutting	Low	×	×	×	×	×	×	×	×	×	×	×	×	×	○	●	×	●
	Moderate	×	×	×	×	×	×	×	×	×	×	×	×	×	○	●	×	●
	High	×	×	×	×	×	×	×	×	×	×	×	×	×	○	●	×	●
Instability Rutting	Low	⦿	×	×	○	×	×	×	●	●	●	●	●	●	×	●	×	×
	Moderate	×	×	×	○	×	×	×	●	●	⦿	⦿	●	●	×	●	×	×
	High	×	×	×	○	×	×	×	○	⦿	⦿	○	⦿	●	×	●	×	×
Alligator Cracking	Low	○	●	●	●	●	○	○	●	●	●	●	●	×	×	●	×	×
	Moderate	⦿	○	○	○	○	○	⦿	●	⦿	●	●	●	×	×	⦿	×	×
	High	○	○	○	○	○	○	○	⦿	⦿	⦿	●	●	×	×	○	×	×
Block craking	Low	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	Moderate	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	High	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Shoving		×	×	×	×	×	×	×	○	○	⦿	○	○	×	×	●	×	×

●-Appropriate ⦿-May Be Appropriate ○-Not Appropriate ×-Not a Candidate

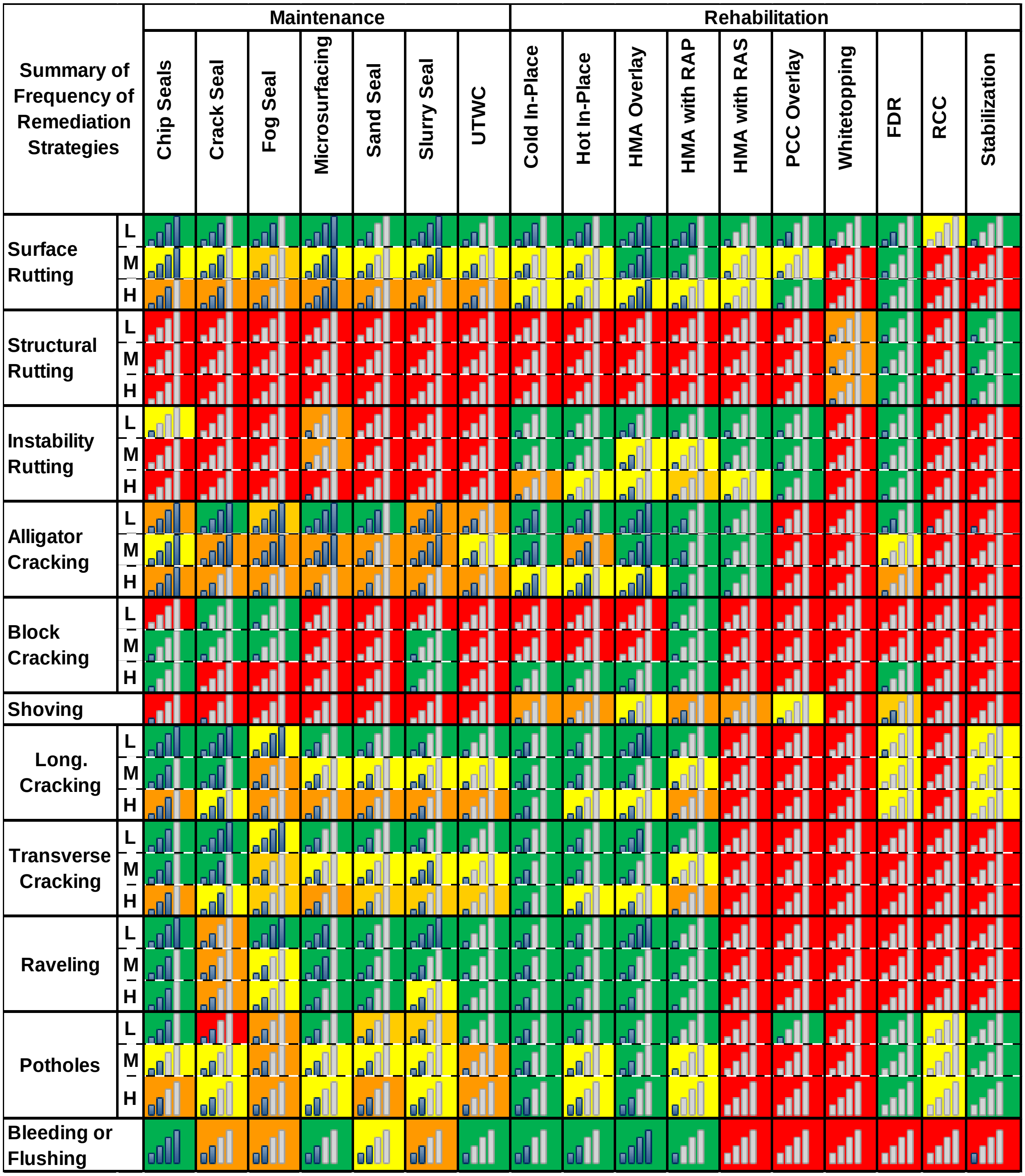
MicroS. - Microsurfacing
UTWC - Ultra Thin Wearing Coarse
RAP - Reclaimed Asphalt Pavement
RAS - Recycled Asphalt Shingles
UTWT - Untra Thin White Topping
FDR - Full Depth Reclamation
RCC - Roller Compacted Concrete
Stab. - Stabilization

V - Traffic Range Varies from Low to High
M - Traffic Range Varies from Low to Medium

Figure 4.5 – A Sample Matrix Relating Distress to Appropriate Remediation Alternatives

Life Cycle Cost Analysis

Based on the predominant distress, level of severity if required a number of remediation strategies can be identified internally. However, the traffic data and other information are also used to narrow the choices LCCA is used to quantify the total economic value of a project over its life. The main purpose of LCCA is to evaluate the long-term repercussions of initial remediation cost and future maintenance necessary to maintain an acceptable service level for a specified time. The parameters used for the LCCA include initial costs, future maintenance costs over the life of the project, and salvage value at the end of the analysis period. This research is focused on rural road intersections with low daily traffic and also, in many cases users' cost is not readily available. Therefore, users' costs (user delay costs, vehicle operating costs, and crash costs) and the construction activity timing were omitted from the analysis.



Appropriate (coded green)
May be appropreiate (coded Yellow)
Not recommended (Coded Orange)
Not a candidate or no information provided (red coded)

UTWC - Ultrathin Wearing Course
HMA OVERLAY - Hot Mix Overlay
HMA with RAP - HMA with Recycled Asphalt
HMA with RAS - HMA with Recycled Asphalt Shingles
FDR - Full Depth Reclamation
RCC - Roller Compacted Concrete

Figure 4.6 - Summary Matrix Relating Distress to Appropriate Remediation Alternatives

Unit costs and expected lives of each alternative were collected from the literature and provided in the program as default values for the analysis; however the opportunity of adjusting those values to users is feasible. After having identified the problem and provided the list of alternatives a table with the default unit costs is provided right next to each alternative. At this point, users can modify the cost. From the two types of remediation alternatives (rehabilitation and maintenance) the option of selecting a maintenance method for the future is only given to rehabilitation alternatives. The maintenance alternative costs and life expectancy may also be changed at this point, and the time for first maintenance can be selected. When maintenance is an alternative, the same maintenance method is assumed to be used along the analysis time.

The analysis period is essential for the LCCA. To compare the recommended alternatives economically, it is necessary that all alternatives are under the same analysis period. The expected life of each initial remediation alternative is used to determine the starting time for future maintenance, and the expected life of the maintenance method selected is used to determine the timing between maintenances under the analysis period.

The cost of each alternative is easily calculated with the total area to be repaired by the unit cost of construction and materials provided. While the initial cost remains the same, all the future costs (including salvage value) are adjusted to present value with Equation 2.1 by using the discount factor provided by users and the accumulated time from the beginning of analysis. There will be as many future costs as the times the maintenance life expectancy fits in the analysis period. Salvage value is calculated as the remaining value of the last maintenance when it still has a remaining life over the analysis period. Salvage is also adjusted to present value and is subtracted from the cost summation. The equations used to calculate the present value or discounting are provided in Equations 2.1 and 2.2.

CHAPTER 5 - TYPICAL FORENSIC EVALUATION

BACKGROUND

The intersection of SH 49 and SH 155 is located in the Atlanta District (Figure 5.1 and 5.2). This intersection was identified by district personnel as a potential location due to the severity of distresses around the intersection area. This is a rural intersection with a 4-way light signalization consisting of flexible pavement only. The typical cross section is presented in Figure 5.3. The SH 155 pavement section consisted of a 2 in. asphalt concrete pavement (ACP) over 11 in. of base, with the upper 8 in. being lime treated. The SH 49 pavement section consisted of a 4 in. ACP layer over 12 in. of lime treated base over subgrade. A soil report of the intersection and surroundings was obtained from the Natural Resources Conservation Service (NRCS) website. The type of soil in the area is classified as Bowie fine sandy loam.

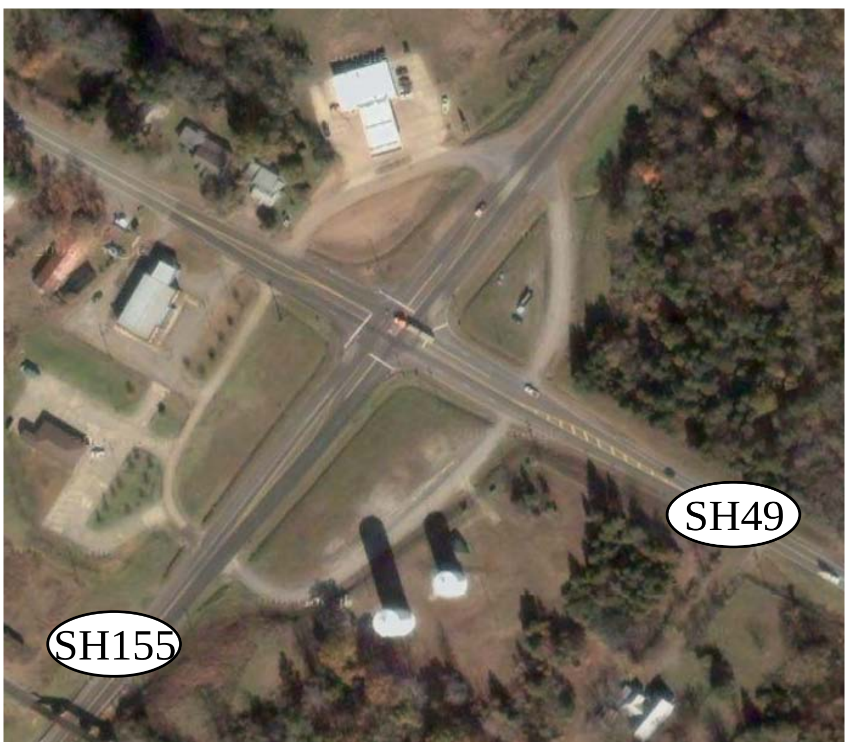


Figure 5.1 – Aerial View of SH 155 and SH 49 Intersection.

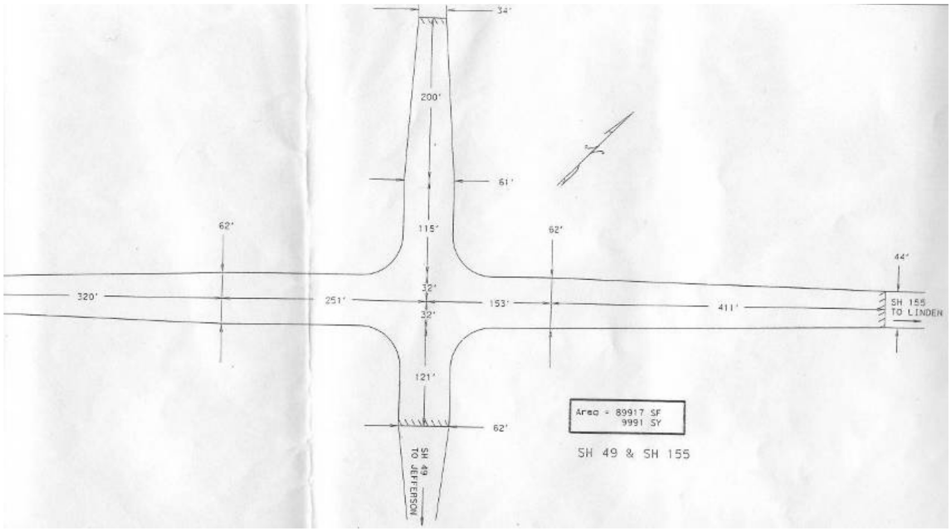
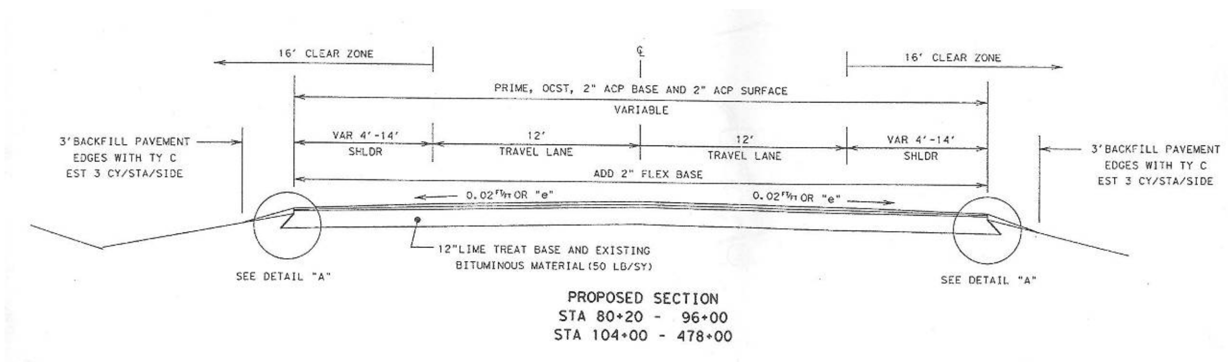
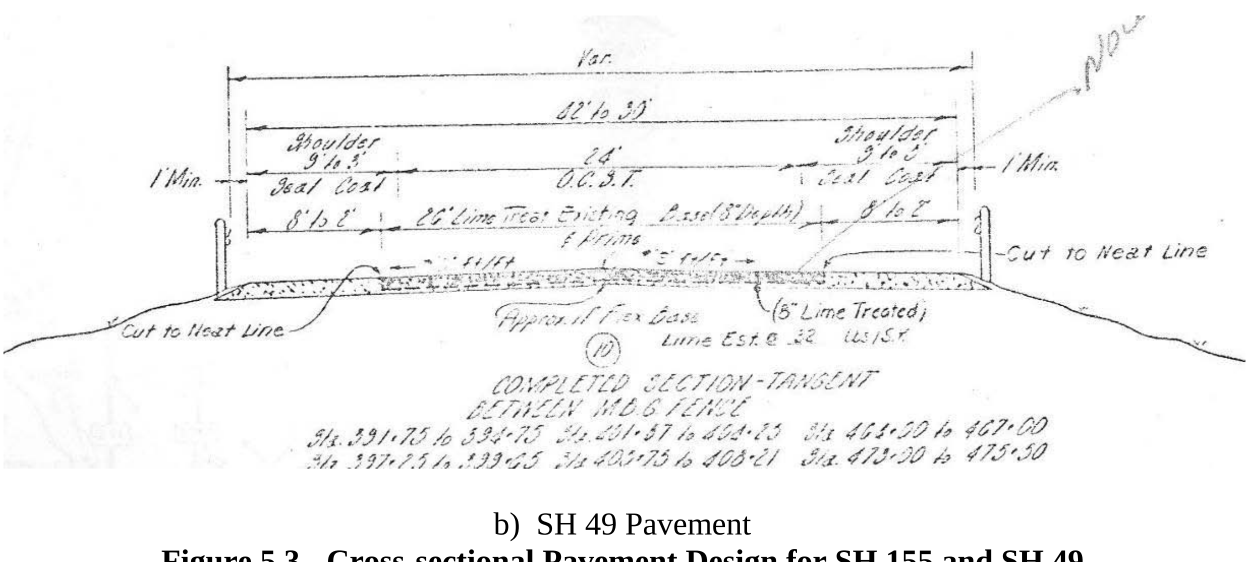


Figure 5.2 - Geometry of SH 155 and SH 49 Intersection.



a) SH 155 Pavement



b) SH 49 Pavement

Figure 5.3 - Cross-sectional Pavement Design for SH 155 and SH 49

CONDITION SURVEY

Figure 5.4 shows different views of the intersections along SH 155 with visible distresses. With the assistance from the District personnel, 500 ft sections of the road on either side of the intersections were closed to traffic. A thorough inspection was carried out on all legs of the intersection. The primary distresses observed were rutting of the surface layer. The intersection, at the southbound approach on SH 155 was rutting. No humps could be seen on the sides of the ruts. As such, it can be assumed that it might not be a mix problem, but maybe structural rutting. Loss of aggregate was evident on the rutted areas as well as some bleeding and flushing between wheel paths.

As shown in Figure 5.5, the maximum rut depth was 0.5 in. on SH155. This distress can be classified as Moderate Severity Structural Rutting. Another distress observed was fatigue cracking with low to high levels of severity, increasing in severity as one approached the intersection. Other distresses included transversal and block cracking specially after crossing the intersection.

Figure 5.4 - Views of the Conditions of SH 155 and SH 49 Intersection.

Figure 5.5 - Rut Depth Measurement on SH 155.

The first 300 ft of SH 49 consisted of a different asphalt mix than the mix closer to the intersection. On the west side, close to the intersection on the eastbound SH 49, a section of approximately 42 yards in length had been milled so no rut profile could be taken in that area. Based on the cores, several lifts were added over time to this intersection. Cores were not extracted from the milled section. It is suspected that the section was heavily rutted and the maintenance crew had overlaid that portion. In addition, transverse cracking could be seen all the way along the 500 ft approach while severe block cracking was seen at the intersection. In some areas, the severe block cracking contributed to generation of secondary distresses as depicted in Figure 5.6.

Figure 5.6 - Cracking Resulting in Potholes on SH 49.

DATA COLLECTION

For coring purposes, four strategic locations were selected, 2 locations per road, with one location 500 ft away from the intersection, and the other location within 100 ft of the intersection, all in the approaching lanes. Three cores were extracted from each location, one on each wheel-path and one between the wheel-paths, making it a total of 12 core extractions as marked in Figure 5.7.

Figure 5.7 - Location of the Core Extractions.

Deflection data were collected using a Falling Weight Deflectometer (FWD). FWD data along SH 155 were collected from 500 ft north of the intersection to 500 ft past the intersection. Data was collected at 25 ft intervals except in the vicinity of the intersection where data was collected more densely (see Figure 5.8a). The same was performed for SH 49, starting 500 ft west of the intersection (see Figure 5.8b). An air-launched Ground Penetrating Radar (GPR) was also used along these two roads.

Figure 5.8 - FWD Collection on SH 155 and SH 49 Images.

DATA ANALYSIS

Core Analysis

Figure 5.9 shows the coring process and a sample of the cores that were extracted. Cores were extracted from 4 locations as mentioned before, locations 1 and 2 were on SH 155, while locations 3 and 4 on SH 49. Dimensions and weight of every core were measured, and the V-meter test was performed on each sample to calculate the modulus of the asphalt layer from different locations. The asphalt content of each core was determined using an ignition oven. Sieve analysis was carried out on the retrieved aggregates from the oven to determine the gradation. Summaries of the analyses, results and images of each core extracted are included in Appendix G.

Figure 5.9 - Coring Process Images.

The average thickness of each set of cores is plotted in relation with the distance from the intersection in Figure 5.10. The error bar indicates low variability in the thickness of the four sets of cores, except for the first set of cores extracted 500 ft north from the intersection on SH 155. A decrease in thickness approaching the intersection is evident along SH 49, while on SH 155 the asphalt layer thickness seems to remain constant. The surface layers of the two sets of cores from SH 49 were different. Severe stripping was observed in the cores away from the intersection along SH 155 that might have prompted maintenance. The modulus trends as approaching the intersection are the opposite of the air voids for both roads as seen on Figure 5.11.

In order to verify the lime stabilization of the bases, phenolphthalein was used. The reaction occurred just on the second and third sets of cores as seen in Figure 5.12, but no reaction occurred on the first or fourth set of cores. An intact base core could only be extracted from the third location. Higher lime content was perceived for the third location.

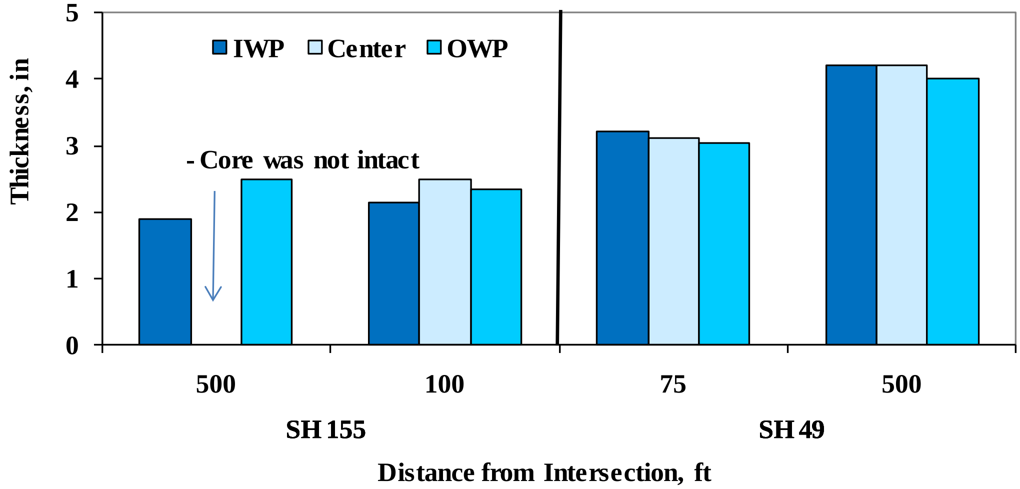


Figure 5.10 - Core Average Thicknesses as Approaching the Intersection.

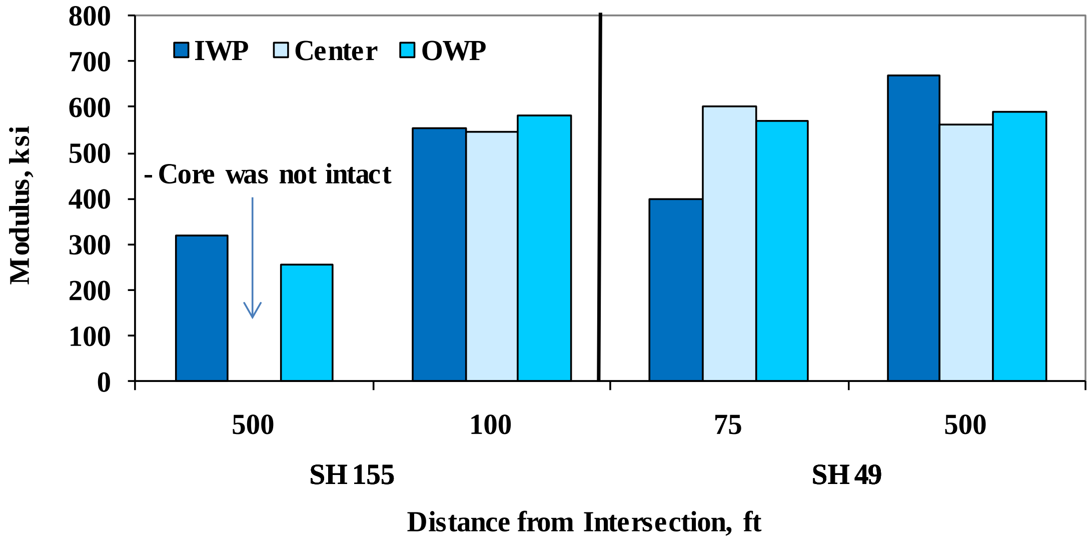


Figure 5.11 - Core Average Modulus as Approaching the Intersection.

a) Set 2 on SH 155 b) Set 3 on SH 49 c) Set 4 on SH 49

Figure 5.12 - Phenolphthalein Test for Lime on Base Material.

FWD Analysis

Figure 5.13 illustrates the deflection results obtained from the FWD along the SH 155 section. Deflections from the first two sensors are greater close to the approach of the intersection, indicating lower stiffness of this section of the road. After passing the intersection deflection values decreased dramatically and remained fairly constant. The third and fourth sensors also detected a slight increase in deflection for a 150 ft section before the intersection, providing a clue that the source of the problem might come from the base layer. The last three sensors did not detect a significant deflection, thereby it can be assumed that the source of the problem does not go deeper than the base layer.

Figure 5.14 illustrates the deflections obtained from the SH 49 section. The first 200 ft with a different mix have a considerable lower deflection than the rest of the road. The change in deflection after the first 200 ft remains constant until reaching the intersection, where a decrease

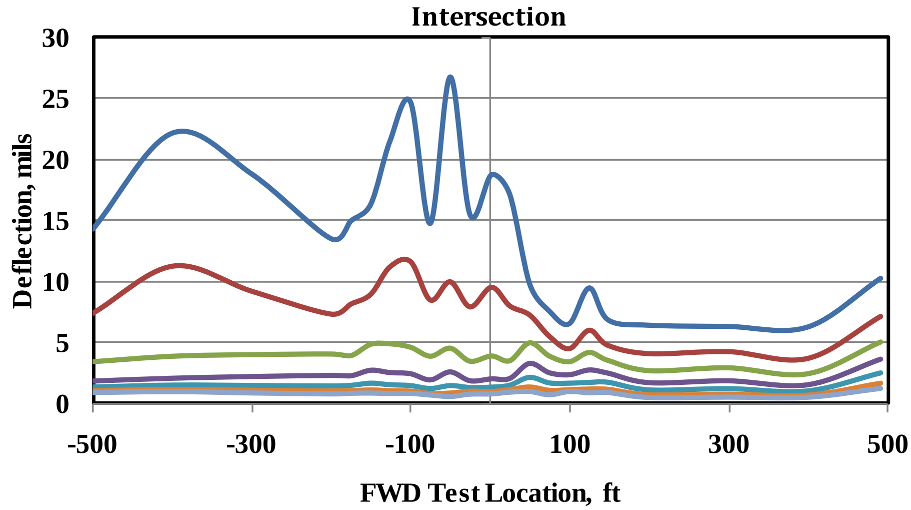


Figure 5.13 - FWD Deflection Results on Eastbound SH 155.

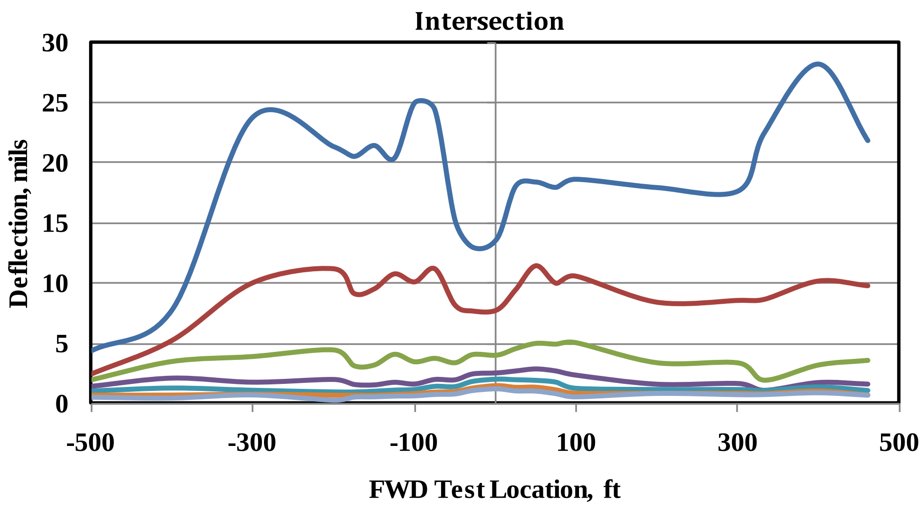


Figure 5.14 - FWD Deflection Results on Eastbound SH 49.

in deflection is observed. After passing the intersection, the deflections increase again to a constant value for the next 250 ft, only a high point is seen 400 ft after the intersection. The structure is more susceptible to deflection along the 300 ft section before reaching the intersection. The third and fourth sensors also detected an increase in deflection as approaching the intersection and slight variations in deflection through the last 200 ft before the intersection. The higher deflections detected by the third and fourth sensors as approaching the intersection are consistent with the lack of stabilization on the fourth coring location (100 ft before the intersection). Although the soil tested from core location 4 (100 ft from intersection) did not showed evidence of lime, contrary to location 3 (500 ft from intersection), no permanent deformation could be seen at this place. The last three sensors did not detect a significant deflection; thereby one can assume that the source of the problem might be no deeper than the base.

GPR Analysis

The PAVECHECK software (Liu and Scullion, 2008), developed to merge the FWD and GPR data together with digital video images of surface condition was used. Figure 5.15 is a sample of the data collected on SH 155 and SH 49 as approaching the intersection.

Figure 5.15 - Sample of the GPR Data Close to the Intersection of FM155 and FM49.

Figure 5.16 contains the GPR, FWD and Core thickness data all together for comparison analysis of SH 155. GPR plot is in terms of thickness of the upper layer, while the FWD data corresponds to the deflection readings of the first sensor. The core thicknesses compared well with the GPR thicknesses. GPR thickness readings are reasonably constant until approximately 30 ft before SH 49 center line, where the thickness increases to over 4 in. and then decreases to 1 in. after crossing SH 49 and slowly increasing its way back to a little over 2 in. along the acceleration section. The constant GPR measured thickness before and after the intersection may be an indicator that the asphalt layer may not be the source of rutting.

Similar results for SH 49 are illustrated in Figure 5.17. As mentioned before, the first 300 ft of the survey consisted of a different asphalt mix. The HMA thickness is about 3.5 in. to 4 in. before the intersection, increasing to around 5 in. past the intersection. The HMA layer thickness at the intersection seems to be controlled by the design of SH 49 but with an additional 0.5 in. slurry seal.

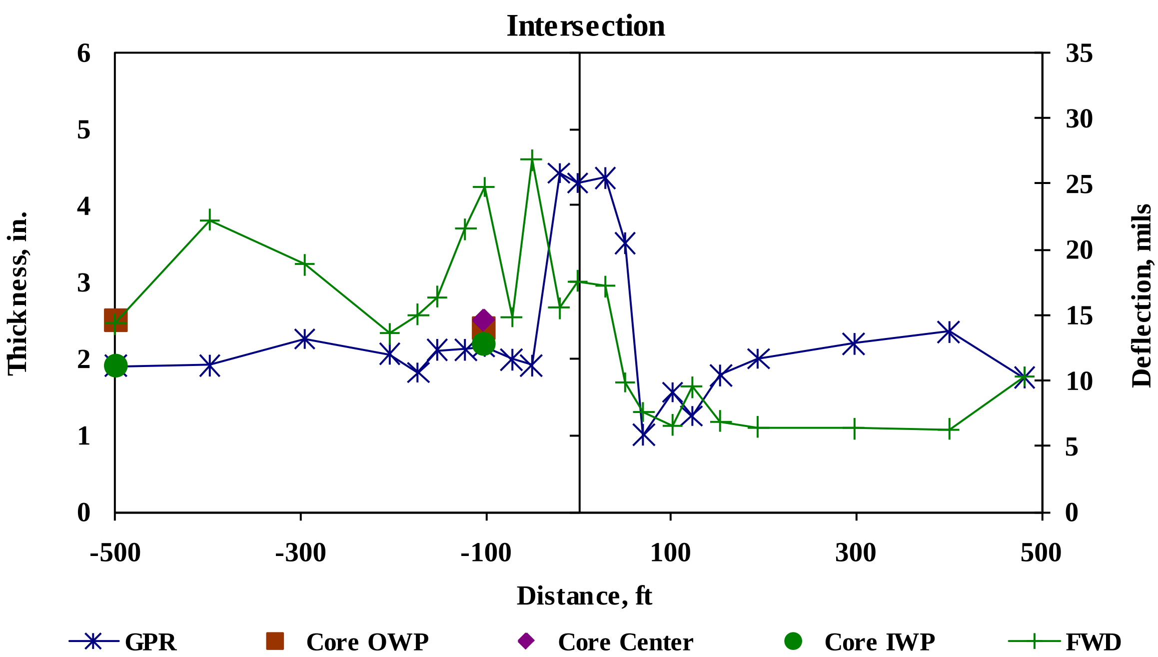


Figure 5.16 - GPR, FWD and Cores on SH 155.

A relationship between thickness and deflection is appreciable. The first half section of SH 49, which is thinner, provides higher deflections, while past the intersection that trend reverses. No rutting appeared on the first half of the road, most likely the severe block cracking is the reason for the high deflection values.

CONCLUSIONS

The evidence from the visual condition survey on SH 155 suggests that the absence of humps on the sides of the ruts indicates that the source of rutting is not the asphalt layer, but an underneath layer. The GPR results corroborate the same assumption by showing a consistency in the thickness of the asphalt layer. Deflections from the first three sensors show that deflections up to the intersection are much higher than after crossing the intersection. These readings from FWD

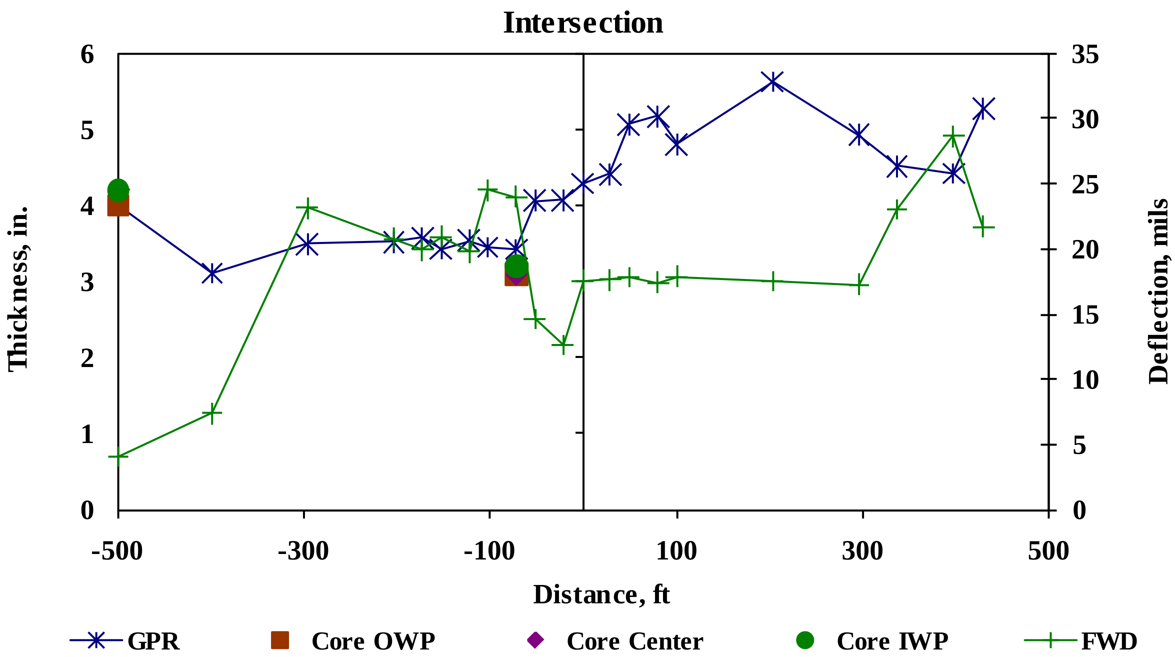


Figure 5.17 - GPR, FWD and Cores on SH 49.

suggest that the problem might be in the base layer. Although some shoving and other asphalt mix related distresses existed, the predominant and "deeper" distress for SH 155 was classified as Base Moderate Structural Rutting.

High Severity Block Cracking was the most visible distress on SH 49. Aging of the asphalt or wrong binder selection could be the causes of the failure. No significant permanent deformation could be perceived on the approach, indicating that the base layer is still in good condition. Also GPR results showed thickness uniformity for the asphalt layer. Severe block cracking might be the source of the high deflection levels detected by FWD.

CHAPTER 6 - CASE STUDY TO ILLUSTRATE USE OF EXPERT SYSTEM

This chapter will serve two purposes. The first is to demonstrate the use of the expert system for selecting appropriate strategies to improve intersections by briefly describing step-by-step the operations of the system. The second is to present a case study using a site from the Atlanta District that was described in Chapter 5 for the selection of an appropriate remediation strategy. In Chapter 5, the field investigation was presented and the dominant distress identified. In this chapter, the selection of appropriate remediation strategies is described.

EXPERT SYSTEM FOR SELECTION OF APPROPRIATE REMEDIATION STRATEGIES

The expert system was developed online using Java application for several. The main reasons are that users need not worry about a) installation of the software, b) future updates, and c) compatibility of the operating system. The expert system can be securely accessed through most browsers from the following link: http://ctis.utep.edu/txdot/intersection/login_form.php.

Figure 6.1 shows a screen shot of the website where users can login. The two products of this research, i.e. the expert system and user's guideline, can be accessed directly from the website. Once the link for the expert system is selected, the tool is launched on the website. The tool is separated into two sections: a) header and b) the tabular panel as presented in Figure 6.2. The header portion remains static as users navigate through the tool. The header includes features such as "*Save and Load Project Information*", "*Online Manual*" and "*Online Guideline*" links that allow users to retrieve and save a project file, access user's manual for this tool, and to access user's online guideline, respectively. The bottom portion of the webpage is the tabular panel that provides menus to utilize the expert system and process information for selecting strategies for remediation alternatives at intersections. This process is presented next.

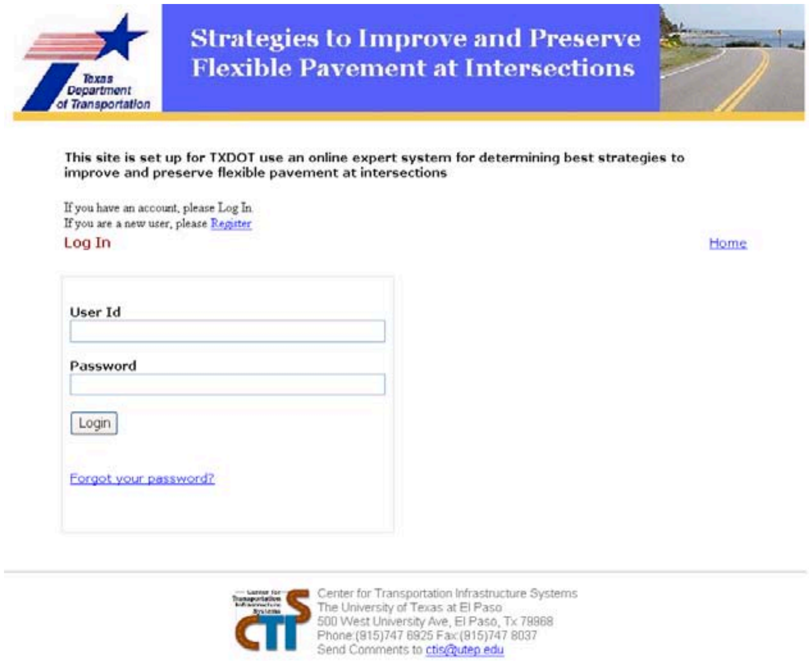


Figure 6.1 - Restricted Online Expert System Login Screen.

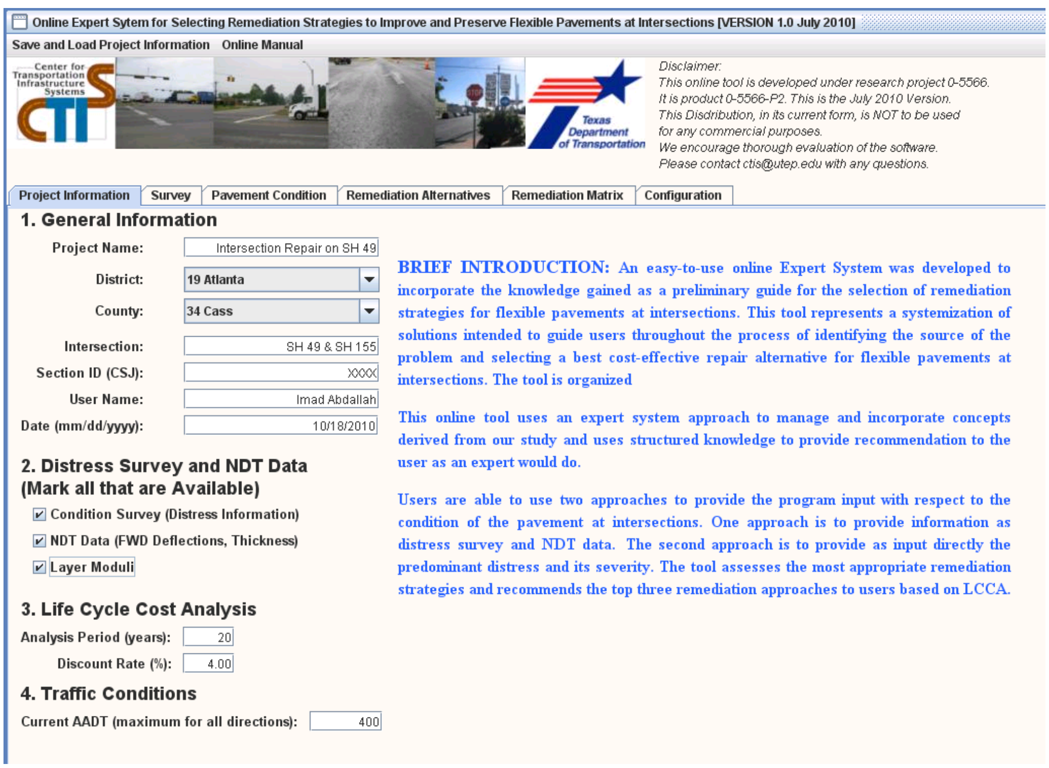


Figure 6.2 - Section No. 1 with General Project Information.

Input Modules

The tabular portion contains the following main components of the expert system which will be discussed in this chapter:

- Project Information
- Survey
- Pavement Condition
- Remediation Alternatives
- Remediation Matrix
- Configuration

Project Information

The "*Project Information*" tab is what gets launched when the tool is loaded. The information tab on the main screen requires input from users on the following items:

- General Information
- Distress Survey and NDT Data
- Life Cycle Cost Analysis
- Traffic Conditions

The first step as presented in Figure 6.2 requires trivial input such as project name and location. The next step is with regard to the distress survey and NDT data (when available). Users are able to check each option where the information is available. In this case study, all information was available and therefore all options are selected. The last two steps, Steps 3 and 4, are information for the LCCA and traffic, respectively. As depicted in Figure 6.2, the LCCA information required is the analysis period and discount rate. The traffic information required is the AADT. For this case study, the analysis period is set to 20, the discount rate is defaulted at 4% and finally the AADT is 400.

Survey

The next tab is the "*Survey*" tab that contains the condition survey and the NDT results from a field investigation. The information provided in this tab is to be used to support the engineer's decision to select the predominant distress. It is important to note that this information is one of the ways of identifying predominant distresses at intersections. For the purpose of this case study and illustrating the function of this module, the main distresses observed at the site and the results from the FWD data are loaded into the "*Survey*" tab as shown in Figure 6.3.

The "*Survey*" tab has three sections: a) condition survey, b) distress description, and c) NDT results. Figure 6.3 present two of the three sections. The condition survey section on the left hand side of the webpage has information such as total length of the distressed area and common types of distresses at intersection. Users enter the amount or quantity of distress (length or area) in the corresponding severity level for each distress. The guide to measure distress and severity level was presented in Table 4.1. Once distress information is provided, the tool internally calculates the percentage of distress and prioritizes the results based on a weighted average to

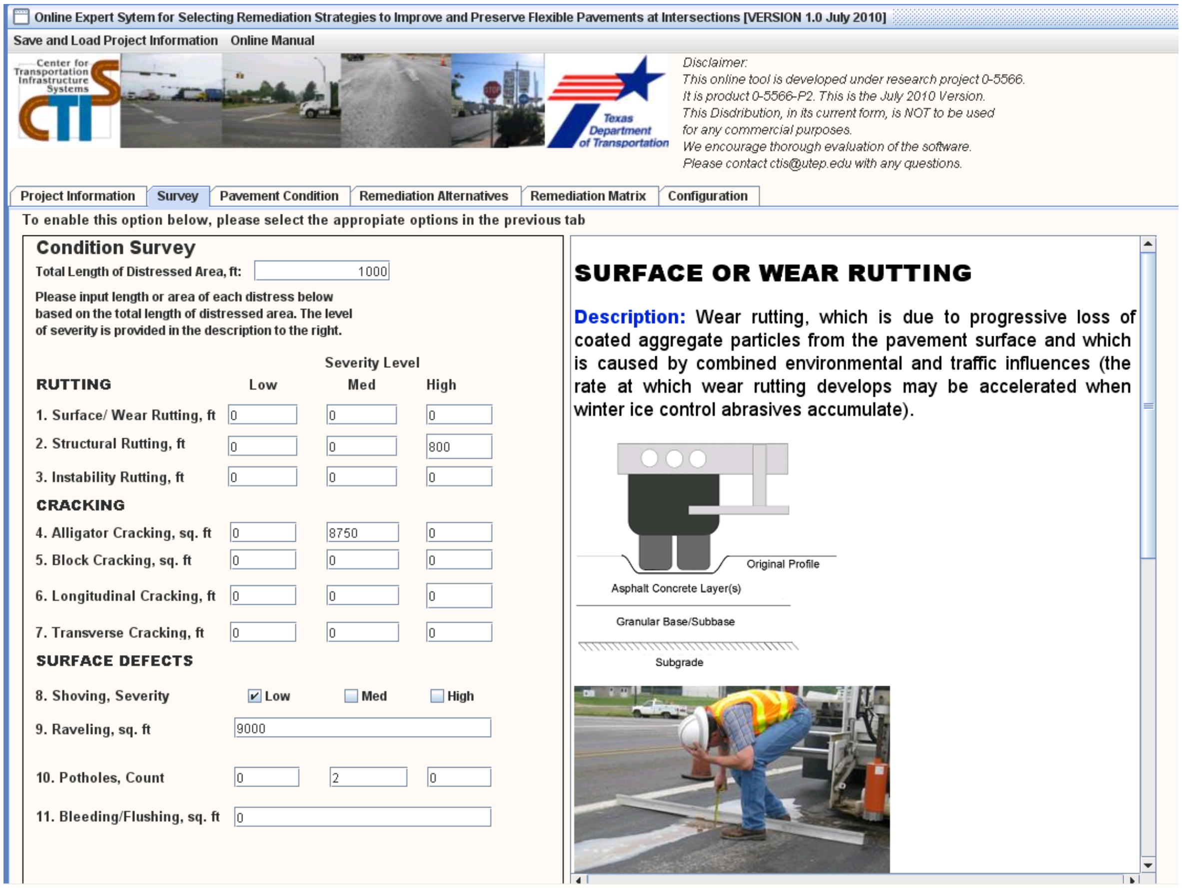


Figure 6.3 - Survey Tab of the Expert System.

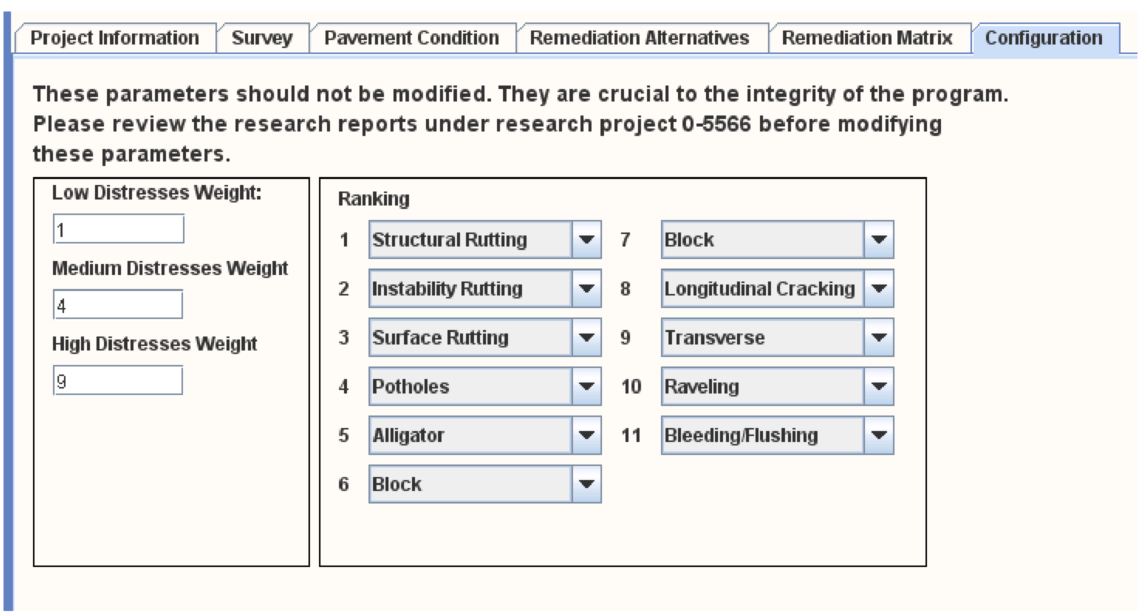


Figure 6.4 - Configuration Tab of the Expert System.

determine predominant distresses. The weights of the severity levels and ranking of distresses are incorporated in the "*Configuration*" tab and presented in Figure 6.4. Although these values are available and can be modified by users, they should not be modified without thorough understanding of the algorithm for determining the predominant distresses.

The algorithm to compute the distresses is as follows:

1. A score for each distress is computed by taking the ratio of the distress measured over the total length or total area depending on the type of distress for each severity level.
2. The estimated ratio is multiplied by the weight assigned to each severity.
3. The sum of the product is calculated to estimate the total score assigned to each distress.

The higher the score is the more dominant a distress will be. In addition to the total score, the severity level assigned to a distress is the maximum distress that is reported by users in the survey. The top three dominant distresses with assigned severity level are reported back to users for a decision which predominant distress to select. In case of a tie in the total score, the ranking provided in Figure 6.4 is used to break a tie.

Another important piece of information that is provided to users is detailed description of each distress. The section on the right side of the list of distresses in Figure 6.4 provides a description and illustration of each distress. Users can read detailed description of any of the distresses listed simply be selecting the distress type on the left hand side.

The last portion of the "*Survey*" tab is the NDT data. In Figure 6.5 the NDT data information is presented. The parameters for the NDT data are deflections, layer thicknesses and layer moduli. The information required are the typical values or "critical values" that represent the pavement condition at the intersection. The values listed in Figure 6.5 were used to diagnose the structural deficiency if any for this case study.

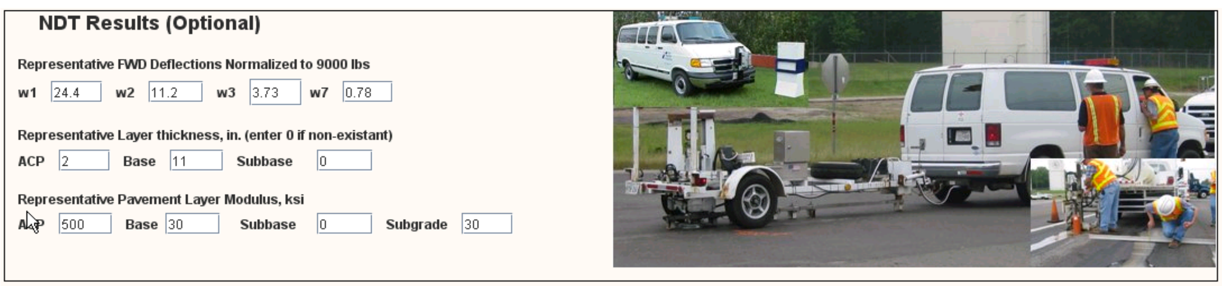


Figure 6.5 - Survey Tab of the Expert System Highlighting the NDT Input Section.

Pavement Condition

The next step in this expert system is for the users to review the results or recommendation from the survey and NDT results provided in the "*Pavement Condition*" tab. Figure 6.6 highlights the information in the "*Pavement Condition*" tab. This tab provides information for Step 5 and 6 of the process. Basically, providing users with recommendation of the predominant distress and allowing users to select the distress and severity for processing the most appropriate remediation alternatives.

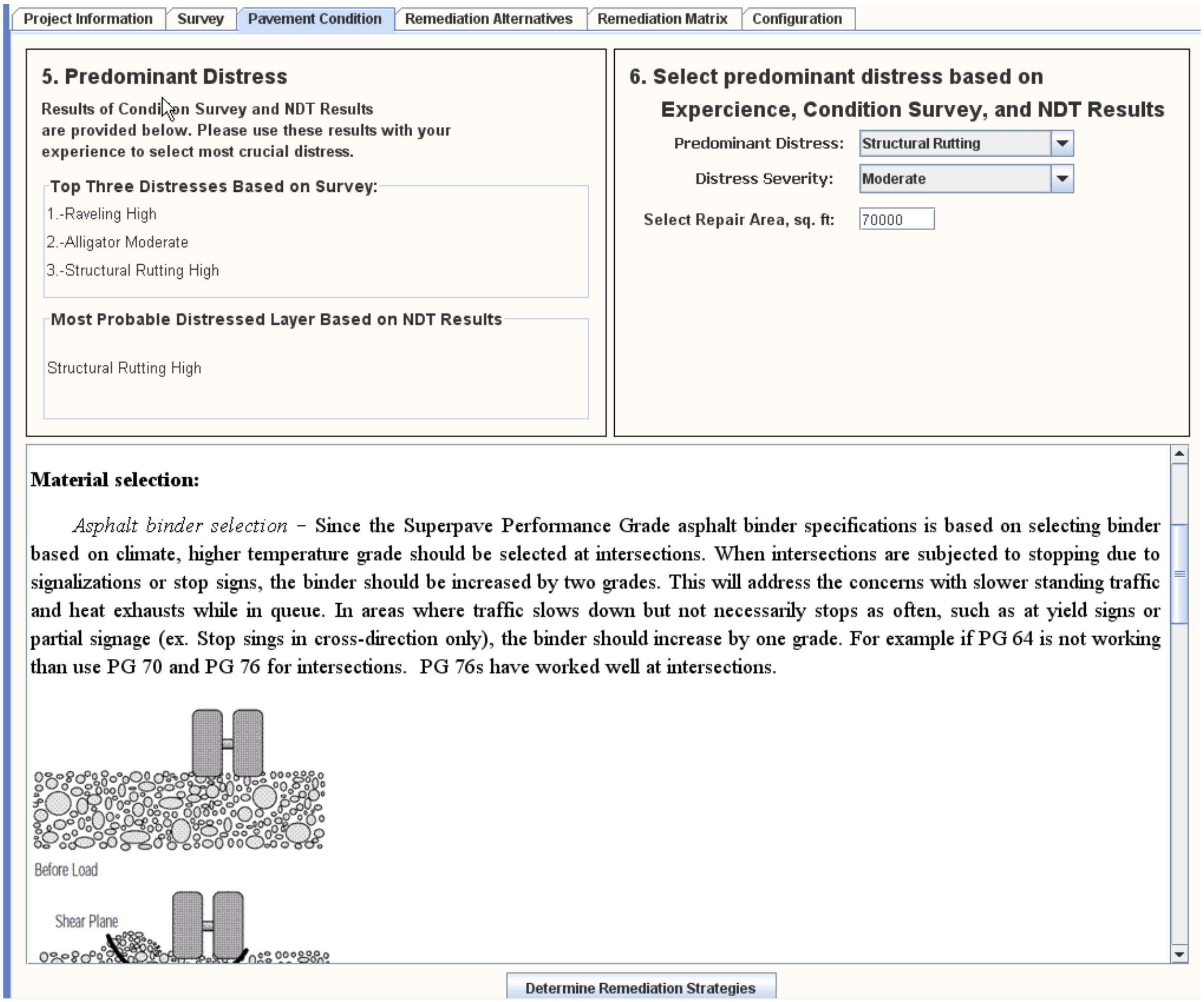


Figure 6.6 - Pavement Condition Tab of the Expert System.

Figure 6.6 shows that the three main distresses and corresponding severity identified from the survey were high raveling, moderate alligator cracking and high structural rutting. The results of NDT data signified potential structural problem in base.

In order to proceed and determine the most suitable remediation alternatives, user intervention is required in Step 6 "*Select Predominant distress based on experience, condition survey and NDT results*". This was purposely design to allow the users to be the decision makers. It is up to the users to make the final judgment as depicted in Figure 6.6.

There is another piece of information that is critical to users to review before proceeding in the process. This information is the special consideration for structural remediation. The information is listed below Steps 5 and 6 in the "*Pavement Condition*" tab. This information relates to material selection, design and construction consideration specifically relevant to intersections. This information was gathered during the research and is provided by the knowledge base of the expert system.

Once the predominant distress is selected and the special considerations are reviewed, the users can select the "*Determine Remediation Strategies*" button to analysis and retrieve the feasible solution from the knowledge base of the expert system. The results are provided in the "*Remediation Alternatives*" tab.

Remediation Alternatives

The purpose of this section is to present all the possible repair alternatives extracted from the matrix of solutions provided in the knowledge base of the expert system. Figure 6.7 highlights Step 7 of the process, which presents the results of feasible alternatives combined with results of LCCA.

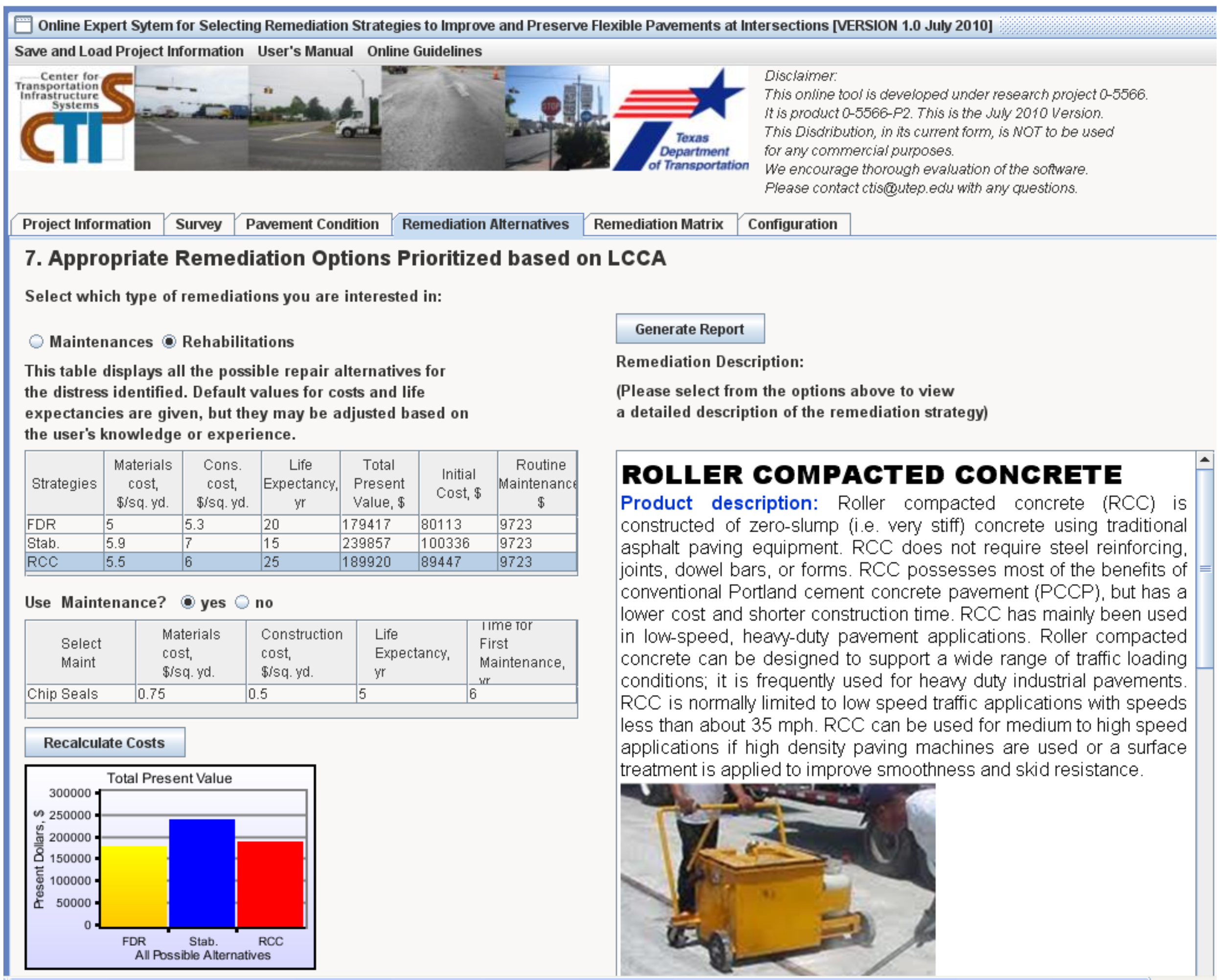


Figure 6.7 - Remediation Alternatives Tab of the Expert System.

First listed is Step 7 is the option for the users to select between either maintenance and rehabilitation option for pavement remediation strategies. The maintenance option is used to retrieve viable option from the knowledge base that can be used to extend the life of the pavement as a short-term fix. The rehabilitation option is more of a permanent or long-term fix of the pavement and can be used to load long term solution from the knowledge base. For either option, the top three remediation alternatives based on the algorithm discussed in Chapter 4 are presented. The other information retrieved in conjunction with the remediation options are the cost associated with material and construction, and life expectancy. The default costs are the state-wide averages that were at the time the tool was developed. These costs can be readily modified at any time based on the users' knowledge of the material and construction costs for their area. The life expectancy, which are based on a nationwide literature review, can also be modified. The cost and life expectancy values for the top three alternatives are summarized in a table listed in Step 7 of Figure 6.7.

The other information in the table of Figure 6.7 are the initial cost, maintenance cost, and total present value. Routine maintenance and associated cost is provided and only used if the rehabilitation option is selected. Users can choose to incorporate routine maintenance in the LCCA. If users opt not to use maintenance in the analysis, the tool provides a means to disable that feature as shown in Figure 6.7. Likewise, if maintenance was selected as the remediation option, the users can decide to incorporate a rehabilitation process in the LCCA. The LCCA used in this tool is based on methodology presented in FHWA (2002 for the evaluation of alternative infrastructure investment options as briefly discussed in Chapter 3.

The three alternatives presented in Figure 6.7 are for pavement rehabilitation. In this case, since the predominant distress is structural, the three alternatives are: a) Full Depth Reclamation, b) Stabilization, and c) Roller Compacted. The total present value of each alternative is included in Table 6.1 and depicted graphically in Figure 6.7. The results show that based on the default costs full depth reclamation is the best alternative with a minimum cost of $ 180,000 for the total present value over a 20-year period. This is based on initial cost of $80,000 and a routine maintenance cost every 5 years of approximately $10,000.

Table 6.1 - Summary of Appropriate Rehabilitation Alternatives

Remediation Strategies	Maintenance Cost, $/Sq. Yd.	Construction Cost, $/Sq. Yd.	Life Expectancy, Yr.	Total Present Value, $ (1000)	Initial Cost, $ (1000)
Full Depth Reclamation	5	5.3	20	180	80
Stabilization	5.9	7	15	240	100
Roller Compacted Concrete	5.5	6	25	190	90

The last two features in the "*Remediation Strategy*" tab are the description of each remediation strategy selected and a button to generate a report (see Figure 6.7). Similar to the distress descriptions, a detail description of each of the remediation strategy is presented (see Figure 6.8). Users can retrieve the description of each remediation by selecting the name of the remediation in the summary table listed in the tab.

CHIP SEAL

PRODUCT DESCRIPTION: A chip seal is a single thin surface treatment constructed by spraying a bituminous binding agent and immediately spreading and rolling a thin aggregate cover. The bituminous binding agent can be emulsified asphalt, cutback asphalt, or asphalt cement. The aggregate used is a single-sized crushed aggregate chip; the maximum chip size is most commonly 1/4 to 3/8 in., although larger chips have been used successfully on roads with heavy truck traffic. The thickness of the constructed chip seal layer is equal to the maximum size of the aggregate chips used. Typical use of chip seal is for road surfacing such as preventative maintenance treatment for small cracks, bleeding, raveling, and loss of surface friction. Chip seals are a widely used alternative for surfacing low volume roads. They protect underlying materials from water and erosion and provide a relatively smooth riding surface. In general, chip seals provide an economical and relatively durable surface that is safe under normal weather and driving conditions. Chip seals can also be placed over new or existing hot asphalt concrete pavement to modify, maintain, or improve the surface texture and friction properties and/or seal small cracks.

TRAFFIC RANGE: Typically AADT< 2,000 (AADT < 1000 when placed on aggregate base, and typical AADT< 2,000 when placed on existing HMA. Also, less than 15% of truck volume is preferred).

LIFE EXPECTANCY: Up to 3 to 7 years.

UNIT PRICE: \$0.80 to \$1.25/yd^2

APPEARANCE: Immediately after placement, the chip seal's appearance is influenced by both the black bituminous binder and the aggregate chip color. If the chips are pre-coated, the chip seal will be black and will not be characterized by the natural aggregate color. A chip seal's appearance can be modified with the careful selection of colored aggregates and by the use of pigments in the binding agent.

ADVANTAGES: Can postpone the need for heavier surface treatments or resurfacing for up to 3 years. Improves surface friction, slows surface raveling and oxidation, corrects minor deformations and seals small cracks, provide temporary cover for a base course until the final asphalt courses can be placed.

LIMITATION: Chip seals should not be applied to pavements with majority of ruts greater than 0.5 in. deep. Preventative maintenance includes periodic crack sealing. Fog seals can be applied to extend the serviceable life of chip seals. Loose chips can be windshield hazard.

LANE CLOSURE REQUIREMENTS: The roadway lane(s) being constructed is closed during construction, so adequate traffic control is needed. The chip seal surface can be opened to traffic at lower speeds as soon as it is constructed. Normal traffic speeds can be allowed once the loose chips have been swept from the roadway surface. Road surface striping may be performed after the lane is opened.

APPLICATION: The bituminous binding agent is sprayed onto the prepared working surface by the distributor; then, the aggregate chips are spread onto the surface using an aggregate spreader. After the aggregate chips are placed, the surface is rolled with a pneumatic-tired roller to embed and realign the aggregate chips in the binder. The surface should be rolled before the binding agent begins to set. The constructed surface should consist of a single layer of aggregate chips with about two-thirds of the voids being filled with the binding agent. The time available for rolling before the binder hardens will depend on the type of binding agent, binder temperature when it is placed, air temperature, and wind, but can range from several minutes to several hours or more. Once the binding agent has hardened, the road surface should be swept with a mechanical broom to remove all loose chips from the surface. A fog seal can be applied to the chip seal after construction to improve the bonding of the chips to the road surface. Provides an economical all-weather surface for light to medium traffic (polymer-modified emulsions and high quality aggregates should be used for higher traffic volume applications). Must be applied to structurally sound pavements.

Figure 6.8 – Sample of the Remediation Strategies provided by the Expert System.

Finally, a summary report can be generated by selecting the button on the "*Remediation Alternative*" tab. This is one of two files saved on user's computer. As presented in the first part of the chapter, the project file can be saved on the user's computer for future use. Figure 6.9 shows the dialogue box that appears when users decide to save the project file. The project file is transferable to any local computer and it can be retrieved from any computer at any time from

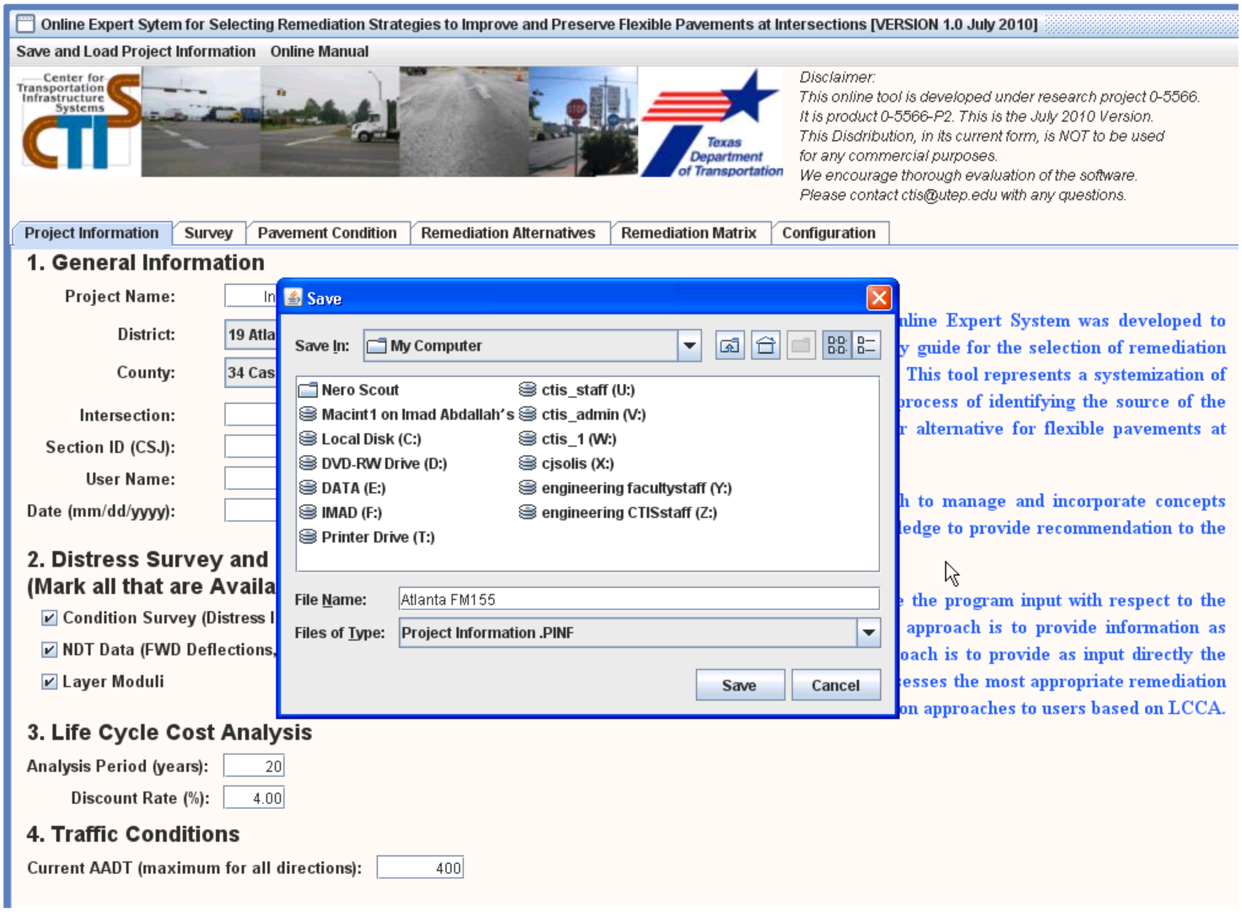


Figure 6.9 - The Saving Feature in the Expert System.

a loading the expert system and loading the file. When the file is selected, the information is loaded to the website.

Finally, users can retrieve the guideline directly using the following link from a browser, http://ctis.utep.edu/txdot/intersection/login_form.php and or can access the online guideline through the button presented in the header of the website. Figure 6.10 presents a screen-shot of the web browser. The online version of the guideline is programmed like an online booklet with feature to zoom in and out, options to print and quickly retrieve any page in the guide. A hard copy of the guidelines is also available for TXDOT personnel. A copy of the online guideline can be downloaded from the following: http://ctis.utep.edu/txdot/intersection/login_form.php .

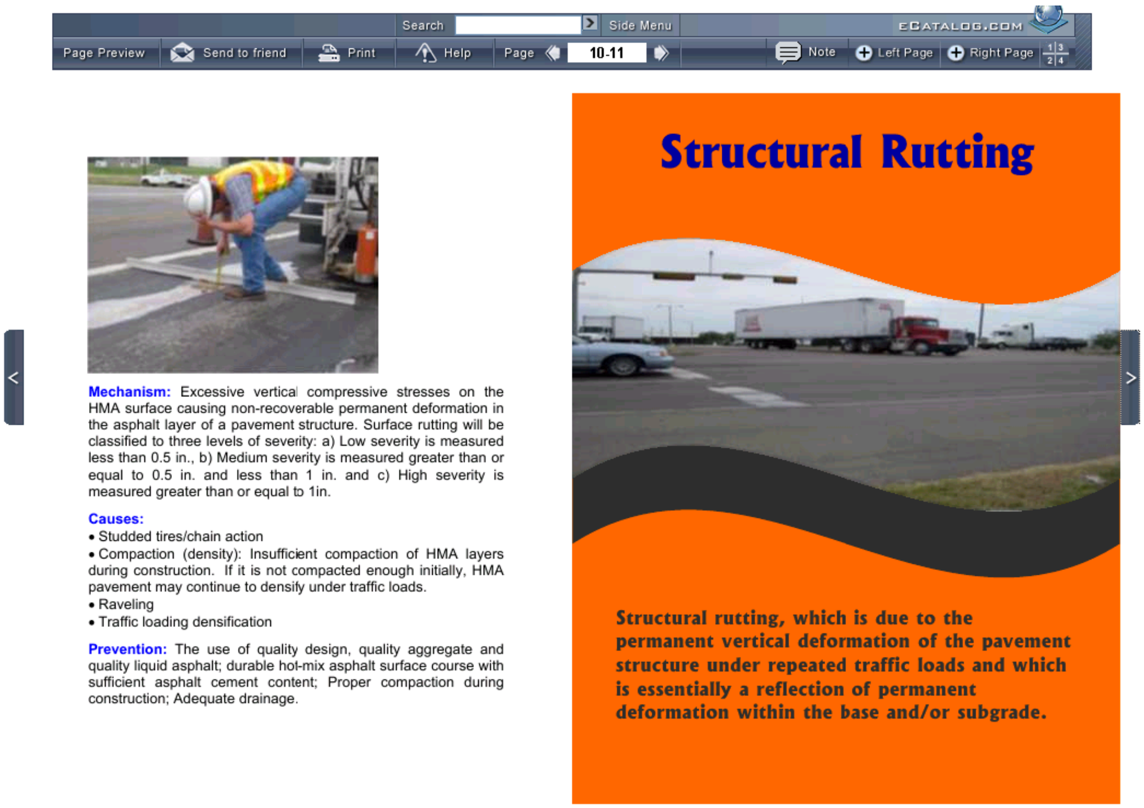


Figure 6.10 - Online Guideline for Strategies to Improve and Preserve Flexible Pavements at Intersections.

CHAPTER SEVEN - PRESENTATION OF RESULTS

A vital part of this research project, was to identify and visit several intersections through the state of Texas. Based on the results of the surveys and interviews several Districts were visited and a total of 10 intersections were selected and investigated. Table 7.1 presents the locations and pavement structure of the sites selected for investigation. Three of the intersections were located in Atlanta, two in Laredo, three in El Paso, and two in Austin. The thickness and type pavement structural layers for each of the intersection are included in Table 7.1. A brief description of each site is presented in the next section followed by the results of the expert system.

Table 7.1 - Summary of intersection Location and Pavement Structure

District	Intersection	Pavement Structure
Atlanta	FM 49 & FM 155	2 in. HMA over 11 in. of base, with the upper 8 in. being lime treated over subgrade
	FM 149 & FM 315	5 in. HMA over 12 in. of lime treated base over subgrade
	US 259&SH 11	4.5 in. HMA over 8in. of base with a 4 in subbase over subgrade
Austin	IH35 & CR210	4in. HMA over 8 in. flexible base over subgrade
	US 281 & SH 29	7 in of HMA over 8 in of flexible base over subgrade
El Paso	US 90& 5th Ave	4 in. HMA over 8in. of black base with 6 in. of stabilized subbase over subgrade
	US 90 West & 6th Ave	3 in. HMA over 6 in. of stabilized subbase over subgrade
	US90 East & US118	4 in. HMA over 8 in. of black base with 6 in. of stabilized subbase over subgrade
Laredo	FM 1472	7 in. HMA over 8 in. of base over 8 in subbase over subgrade
	US 83& IH 35	3 in. HMA over 8 in. of base over subgrade

SITE DESCRIPTION

The first intersection FM 49 and FM 155 of Atlanta District was thoroughly described in Chapter 4 and to avoid redundancy it is omitted here.

Atlanta District: Intersection of FM 149 & FM 355

Figure7.1 depicts the aerial view of the intersection. An inspection at the intersection was performed in April 2009. This is a typical rural intersection with a light signalization consisting of flexible pavement only. The investigation concentrated on the intersection portion of the roadway. With the assistance from the District personnel, 500 ft sections of the road on either side of the intersections were closed off to traffic.

Figure 7.1 - Aerial View of SH315 and SH149 Intersection.

Figure 7.2 shows different views of the intersections along SH149 and SH 315 with visible distresses. The primary distress observed at SH 315 intersection northbound approach was shoving in the surface layer, increasing in severity as getting closer to the intersection. The highest amount of shoving was located approximately 50 ft south of the intersection on the northbound SH 315. The most severe shoving was located at the right turn lane on SH 315. Severe alligator cracking along the wheel path was the predominant distress at SH 149 along with rutting. The most damaged section by alligator cracking was 260 ft south from the intersection on the southbound lane. Ponding was also visible on the side of the road at the time of the visit.

Atlanta District: Intersection of US 259 & SH 11

Figure7.3 depicts the aerial view and drawings of the intersection. A site inspection was performed on May 2009. This intersection is a typical "T" intersection which tops in a "Y" shape.

Figure 7.2 - Views of the Conditions of SH 315and SH149 Intersection.

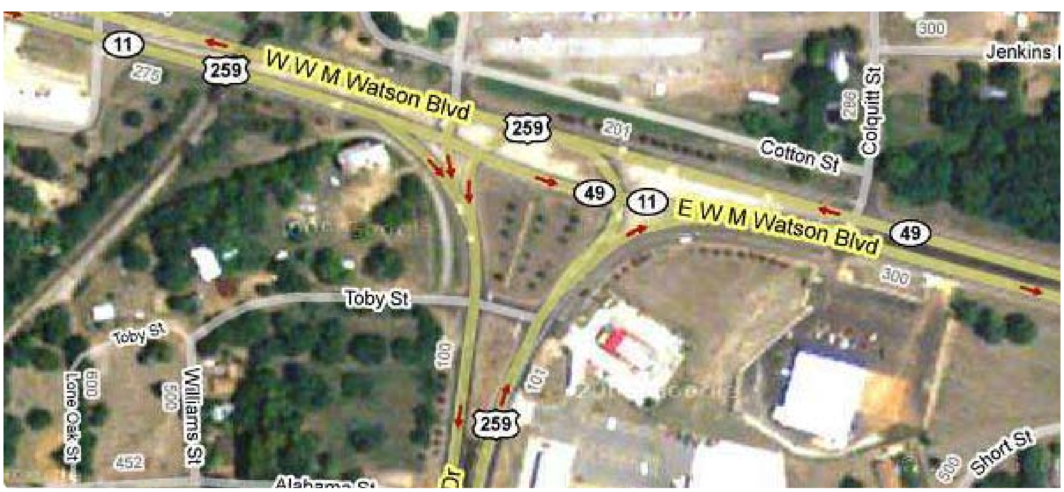
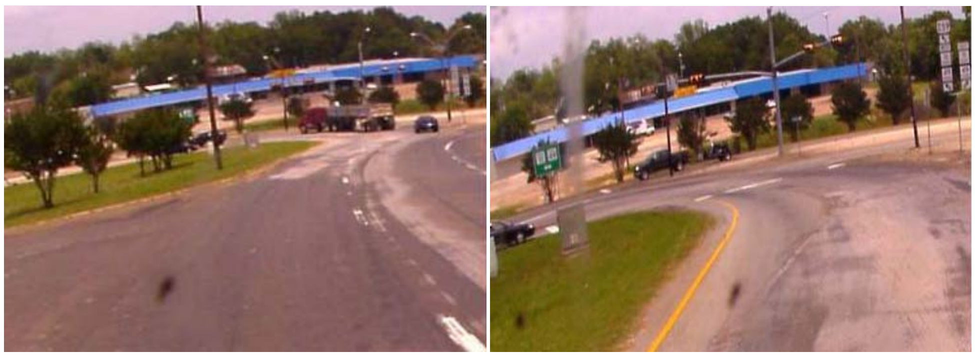


Figure 7.3 – Aerial Layout of US 259and SH 11 Intersection.

With the assistance from District personnel, 500 ft sections of the road on either side of the intersections were closed off to traffic. Figure 7.4 shows different visible distresses. The primary distress observed at US 259 intersection northbound left lane approach was severe block cracking, at right lane approach was low severity transverse cracking, and shoving at the intersection. Also structural rutting or surface rutting was observed on the eastbound right lane and low severity transverse cracking along all four lanes. There was evidence of grinding on the southbound direction of the intersection. Deflection data confirmed that the rutting was in the surface layer. Likewise, some shoving and little rutting on the northbound left lane after the intersection were also found.



a) US 259 Northbound Inner Lane

b) US 259 Northbound Outer Lane

c) SH 11 Southbound Inner Lane (left) and Outer Lane(right)

Figure7.4 - Views of Conditions of US 259and SH 11 Intersection.

Austin District: Intersection of IH 35 & CR210

Figure 7.5 presents the typical distresses at the site in July 2010. The IH 35 portion was sound and no major distresses were observed. The portion of the intersection that is in consideration in this case is the CR 210 lanes. The primary distress covered most of the section was severe alligator cracking. Other distresses observed were shoving, raveling and flushing. The results from the deflection and GPR data show the substructure to be intact.

Figure 7.5 - Conditions on IH 35 and CR 210 Intersection.

Austin District: Intersection of US 281 & SH 29

Figure7.6 depicts the major distresses of the intersection in July 2010. This intersection, which is located in Burnet County, is a major intersection with a very high traffic volume.

Figure 7.6 - Conditions of US 281 and SH 29 Intersection.

The investigation concentrated on SH 29 portion of the intersection since it was more distressed than others. Figure 7.6 shows different views of the intersections along SH 29. The primary distress was severe rutting. The coring profile showed over an inch rutting in the wheel path supporting an indication of surface rutting. This was supported by the results from GPR and FWD. Other distresses observed were alligator cracking and raveling. Structural rutting was observed on the eastbound right lane and low severity transverse cracking on all four lanes. There was evidence of grinding on the southbound direction of the intersection. Some shoving and rutting were also found on the northbound left lane after the intersection.

El Paso District: Intersection of US 90 East & 5th Ave, Intersections of US 90 East & SH118, and Intersection of US 90 West & 6th Ave

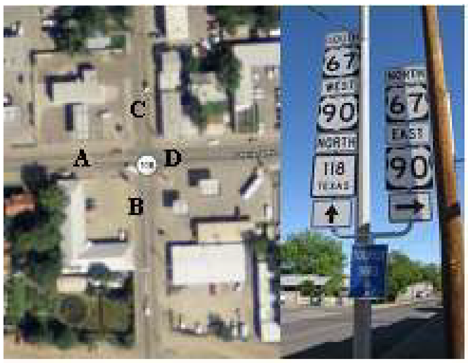
The three intersections were located with less than 1 mile of each other in Alpine. The Intersections of US East 90 East and 5th Ave and US 90 West and 6th Ave were located diagonally from each other. The intersection of US 90 East and SH 118 is located three blocks East of US 90 East and 5th Ave. These sections were set to be rehabilitated with 8 in. of asphalt treated base, topped with 8 in. of concrete.

The two intersections on US 90 had the same structure consisting of 6 in. of HMA over 8 in of asphalt treated base (ATB) over 6 in. of stabilized subbase over subgrade. Although, the US 90 West and 6th Ave intersection had similar geographic and loading conditions, the pavement structure was different. This pavement consisted of 3 in. of HMA over a stabilized subbase layer.

Figure 7.7 shows the severity of distress on US 90 East and 5th Ave. The intersection exhibited severe distresses ranging from rutting, alligator cracking, raveling, longitudinal cracking, and potholes. The major distresses on this roadway were in the upper layer and the predominant distress was alligator cracking. Since the site was under reconstruction a trench was available for investigating structural distresses. No structural rutting was observed in the lower layers.

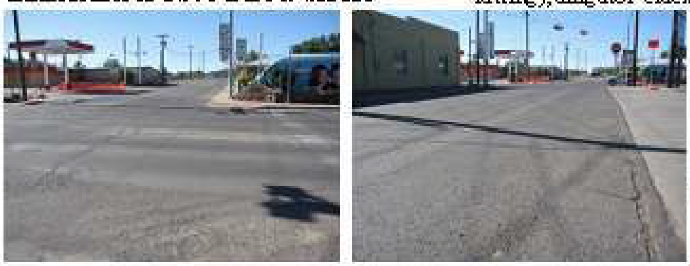
Figure 7.7 - Views of Conditions of Intersection at US 90 East & 5th Ave in El Paso District.

Figures 7.8 and 7.9 provide visual assessment of the conditions of the other two intersections. The US 90 East and SH 118 intersection similar to the intersection on 5th Ave exhibited severe levels of distress. However, since this intersection had four-way stop signs, shoving was the predominant distress. The US 90 West & 6th Ave intersection, similar to the 5th Ave intersection, the predominant distress was severe alligator cracking.



Intersection of US 90 East & SH 118

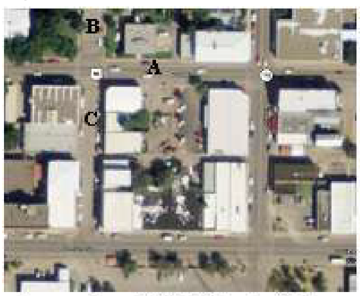
Location (A): US90 W. is one way street
- There are no stop signs, therefore no stop and go. However, major distresses observed are rutting on the wheel path (structural rutting), alligator cracking, raveling and transverse cracking.



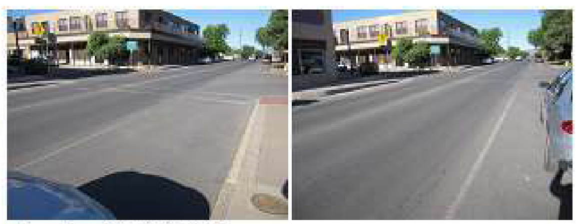
Location (B and C): SH 188
-Severe rutting and raveling.
Also, alligator and longitudinal cracking.

Location (D): US90 East past intersection
-Similar distress as at intersection.
Drainage on both sides of roadway.

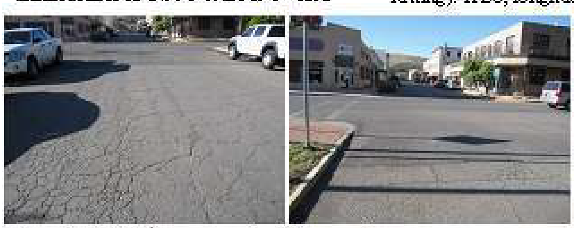
Figure7.8 - Views of Conditions of Intersection at US 90 East & SH 118 in El Paso District.



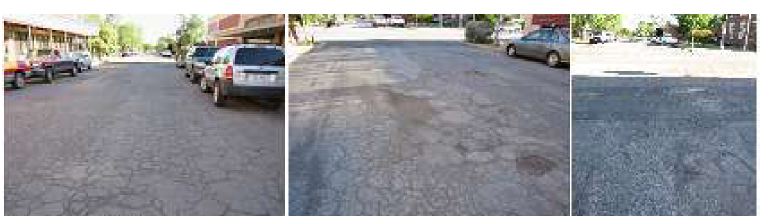
Intersection of US 90 West & 6th Ave



Location (A): US90 W. is one way street
- There are no stop signs, therefore no stop and go. However, major distress observed is rutting on the wheel path(structural rutting). Also, longitudinal cracking outside wheel path.



Location (B): 6th street south of intersection
-Stop sign, severe alligator and block cracking.



Location®: 6th street north of intersection
-Stop sign, severe alligator, block cracking and potholes

Figure7.8 - Views of Conditions of Intersection at US 90 West & 6th Ave in El Paso District.

Laredo District: Intersection of FM 1472 & InterAmerica Blvd

Figure 7.10 depicts the aerial view of the intersection. A site inspection of the pavement was performed by TXDOT personnel. FM 1472 is a 2 lane road that is loaded with heavy truck traffic from the surrounding warehouses. InterAmerica Blvd. runs through the warehouse district ends at the intersection with FM 1472. The "T" shape intersection between these two roads is predicted to have a large amount of traffic with a very high truck ratio. On the 400 ft intersection approach two left turning lanes on both directions were added making FM 1472 an 8 lane road, while InterAmerica Blvd. become a 4 lane road 500 ft before reaching the intersection.

Severe Instability Rutting was by far the most predominant distress on FM 1472 as approaching the intersection. According to the District personnel rutting seems to be the same amount throughout the southbound section, while in northbound the rutting increases as getting closer to the intersection. Alligator cracking was also visible along the wheelpaths, but not a significantly as the rutting. Figure 7.10 shows different views of the intersections along FM 1472. On the southbound direction, the outer left turn lane was the most affected with approximately 1 in. rut depth 70 ft north from the intersection, and 1.5 in. depth 300 ft north of the intersection. In the northbound, rutting started to appear 225 ft before reaching intersection and increased in depth to 3 in. at the stop sign. The rutting in both directions presented humps on the sides, which are the signs of instability rutting of high severity.

Figure 7.10 – Aerial Layout of FM 1472 and InterAmerica Blvd. Intersection.

Figure 7.11 - Views of Conditions of Intersection at FM 1472 in Laredo District.

Laredo District: Intersection of US 83 &IH 35

As shown in Figure 7.12, these roads intersect through a two-way approximately 400 ft long underpass that connects IH 35 off and on ramps with US 83. The most damaged section of the intersection was where the US 83 becomes I-35 southbound frontage road. The east end of the underpass I-35 intersection had been constructed with a PCC pavement. Apparently the underpass has a good drainage system running on the sides.

Multiple distresses were identified on the underpass, but the primary distress was severe alligator cracking specially on the inside lane. Other distresses were flushing, block cracking, longitudinal cracking and rutting. The type of rutting identified was surface rutting. Figure 7.14 shows the severity of the alligator cracking and rutting along the underpass. The rut depths were not measured because of the low severity.

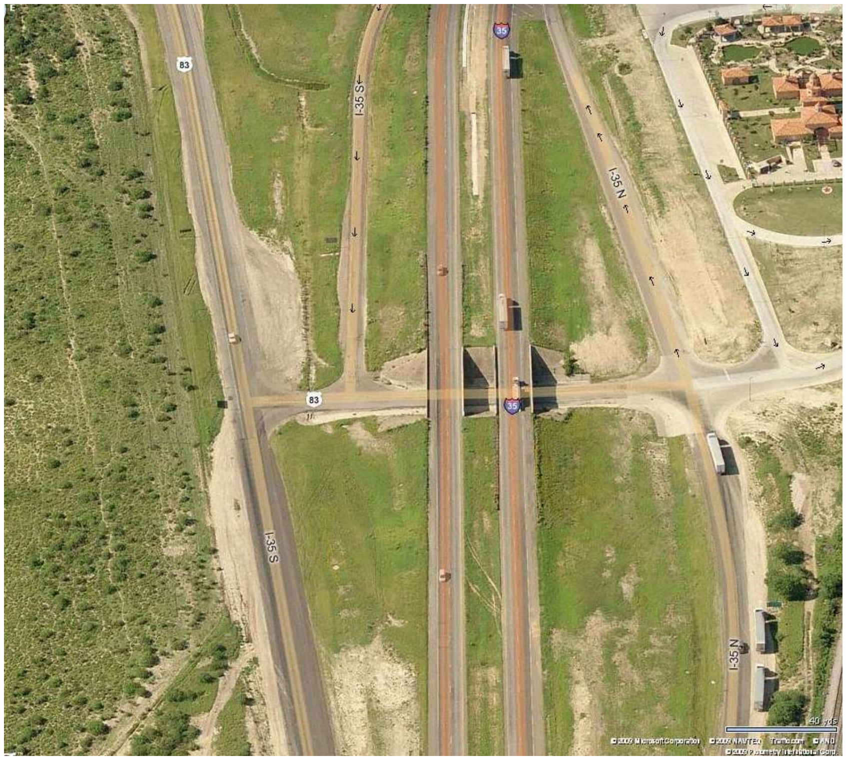


Figure 7.12 – Layout of US 83 and I-35 Intersection.

Figure 7.13 – Views of Conditions of US 83 and I-35 Intersection.

Figure 7.14 – Alligator cracking and Surface Rutting along US 83 Underpass.

RESULTS OF STUDIES AT INTERSECTIONS

Table 7.2 contains a summary the forensic investigation and the results from the expert system for all sites. For each intersection, the information from the forensic study was provided as input to the expert system. The most cost effective remediation alternative based on LCCA is listed in Table 7.2. Two sets of recommendation are provided, one as maintenance (short term fix) and the second as rehabilitation (long term solution). As listed in Table 7.2, the forensic investigation included a condition survey, FWD, and in most cases coring and GPR. These are considered the main investigative tools in TxDOT's arsenal and are important in identifying structural condition. There were few sites where DCP and PSPA were used.

Table 7.2 - Summary of Results Based on the Recommendation of Expert System

District	Intersection	Forensic Investigation	Primary Distresses	Predominant Distress (Layer)	Selected Remediation Maintenance/ Rehabilitation
Atlanta	FM 49 & FM 155	CS, FWD, GPR, Core	Structural Rutting, Shoving, Raveling, Pot Holes	Structural Rutting (Base layer)	NA* / Full Depth Reclamation
	FM 149 & FM 315	CS, FWD, GPR, Core	Shoving, Surface Rutting, Alligator Cracking	Shoving (HMA Layer)	Chip Seal / Hot In-Place Recycling
	US 259	CS, FWD, GPR, Core	Surface Rutting, Block Cracking, Transverse Cracking, Shoving	Surface Rutting (HMA Layer)	Fog Seal / Asphalt Overlay
Austin	IH 35 & CR 210	CS, FWD, GPR, Core	Alligator Cracking, Shoving, Raveling, Flushing	Severe Alligator Cracking (HMA Layer)	Fog Seal / Hot In-Place Recycling
	US 281 & SH 29	CS, FWD, GPR	Surface Rutting, Alligator Cracking, Raveling, Shoving	Surface Rutting (HMA Layer)	Chip Seal / Hot In-Place Recycling
El Paso	US 90 East& 5th Ave	CS, FWD, GPR, Core, PSPA	Surface Rutting, Alligator Cracking, Raveling, Longitudinal Cracking, Pot Holes	Severe Alligator Cracking (HMA Layer)	Ultra-thin wearing Coarse / HMA Overlay
	US 90 East & US 118	CS, FWD, GPR, Core, PSPA	Shoving, Alligator Cracking, Surface Rutting, Raveling, Longitudinal Cracking	Shoving (HMA Layer)	Crack Seal/ HMA Overlay
	US 90 West & 6th Ave	CS, FWD, GPR, Core, PSPA	Alligator Cracking, Block Cracking, Pot Holes	Severe Alligator Cracking (HMA Layer)	Fog Seal / Hot In-Place Recycling
Laredo	FM 1472	CS, FWD, GPR, Core	Instability Rutting, Alligator Cracking, Shoving	Instability Rutting (HMA Layer)	NA* / HMA (Remove and Replace)
	US 83	CS, FWD, Core, DCP	Alligator Cracking, Block Cracking, Longitudinal Cracking, Surface Rutting	Severe Alligator Cracking (HMA Layer)	Fog Seal / Hot In-Place Recycling

NA*- Not applicable or no maintenance strategies were found feasible by the expert system

Summary of Remediation Strategies in Intersections

Table 7.2 shows that different distresses can be exhibited at intersections. As discussed in Chapters 5 and 6 the FM 49 & FM 155 intersection in Atlanta showed structural rutting and the recommendation of the expert system is only to rehabilitate the section using full depth reclamation.

The FM 149 & FM 315 in Atlanta had similar traffic to FM 49 and FM 155 intersection. The section exhibited shoving as the main distress. The maintenance strategy that is most economical was chip seal and rehabilitation alternative Hot In-Place Recycling.

The US 259 & SH 11 intersection in Atlanta exhibited surface rutting as the main distress. The most economical maintenance strategy was fog seal and rehabilitation alternative Asphalt Overlay.

The two intersections in Austin, IH 35 & CR 210 and US 281 & SH 29 one had alligator cracking and the other surface rutting. In the case of CR 210, fog seal and hot in place recycling were the most economical alternative for maintenance and rehabilitation, respectively. On the SH 29 intersection, chip seal and hot in-place recycling were the feasible alternatives.

The intersections in El Paso district showed different predominant distresses. The first two intersections US 90 and 5th Ave and US 90 East and US 118 had the same pavement and both showed that the problem was within the top layer with alligator cracking and shoving as the predominant distress on the pavement respectively. The recommendation from the expert system is to perform an ultra-thin wearing course and crack seal as the economical maintenance strategies for the two intersections respectively. The rehabilitation strategies that cost the least were asphalt overlay for both intersections, respectively.

In the case of the last intersection in the El Paso District, US 90 West & 6th Ave, there were severe alligator cracking. This intersection requires fog seal and hot in-place recycling as the short and long term solutions that are economical.

In the Laredo District both intersections are a “T” shaped intersection with a very large traffic volume and mostly due to trucks traffic. Even though the predominant distress were instability rutting and severe alligator cracking on the intersections of FM 1472 and US83 respectively, due to the traffic volume there were no viable short term fix. The rehabilitation alternative for these intersections was to replace the HMA layer.

It is important to note that the recommendations were not adopted by the districts. The two main reasons were that these intersections were used to study and develop the expert system. Also, the decision repair strategy for each intersection had already been made before this expert system was finalized.

CHAPTER EIGHT – TESTING PROTOCOL AT INTERSECTIONS

Two types of testing, condition survey and field testing are suggested. The condition survey is carried out to identify the lane that shows the most distress to minimize the time and cost of survey. The information in TxDOT Raters Manual and the Distress Identification Manual for the Long-Term Pavement Performance Program from the Federal Highway Administration can be used for this purpose. More effectively, the guidebook developed in this project can be used for identifying the types and severity of the distress and locate the layer(s) that contribute to distress. This information is used as input in the expert system (see Figure 8.1) to assist in estimating the three most predominant distresses. The steps required for this task are the following:

- Record the types of distress (supported with photographs) along the length of the problematic area.
- Estimate the length or the area of the problematic area using a measuring wheel or a similar device.
- Identify the type of distress, if applicable. For example for rutting, there are three types of rutting: a) surface rutting, b) instability rutting and c) structural rutting.
- Quantify the level of severity of each distress type. For example for rutting, there are three levels of severity: a) low severity (less than 0.5 in rut), b) medium severity (between 0.5 in. and 1 in. rut) and c) high severity (1 in. or more rut).

In most cases a visual distress survey is not enough to identify the predominant distress especially if it is a structural problem. If more investigation is needed, nondestructive and destructive testing should be considered. The most common tests consist of the following:

- *Non Destructive Testing*
    - Falling Weight Deflectometer (FWD)
    - Ground Penetrating Radar (GPR)
    - Portable Seismic Pavement Analyzer (PSPA)

- Destructive Testing
    - Trenching or Coring
    - Dynamic Cone Penetrometer (DCP)

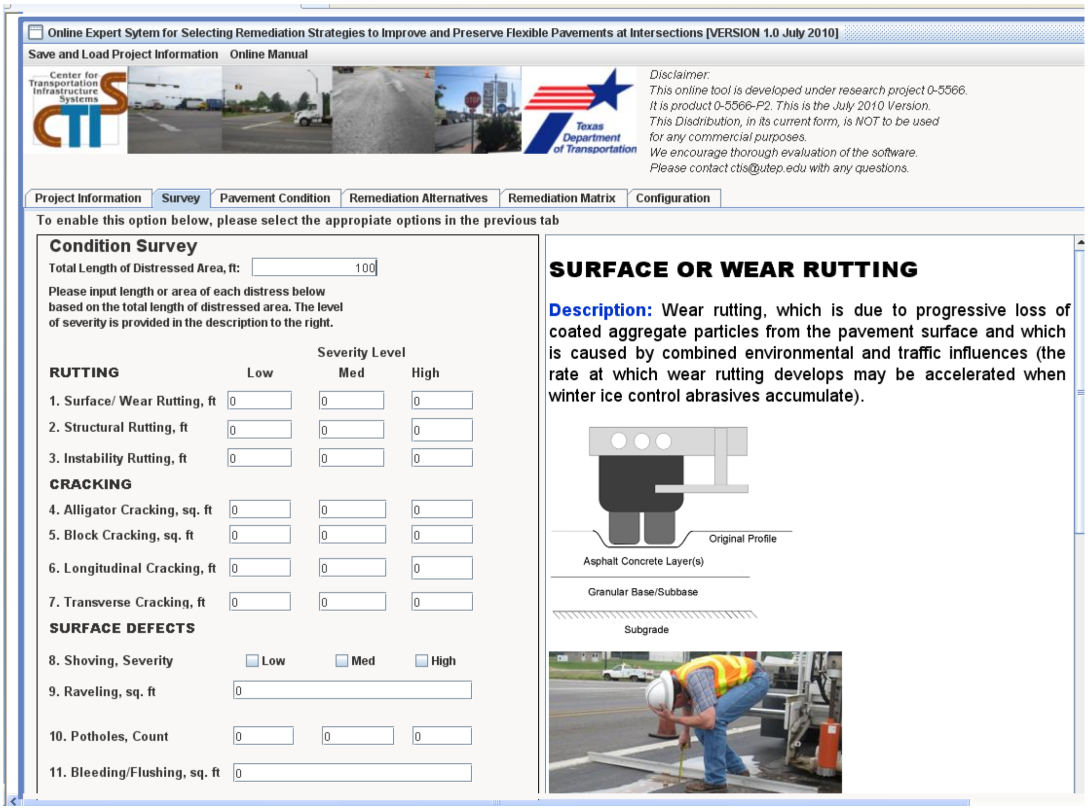


Figure 8.1 - Snapshot of the Condition Survey Module in the Expert System.

The main reason for field testing is to isolate the layer(s) that contribute to the predominant distress, and to obtain field data for evaluating the structural capacity of the pavement. Several tools are available to TXDOT personnel that can be used for this effort. A summary of each method and how it should be carried out at intersections are provided next. It is important to note that each intersection has different considerations and priorities and not all the tools listed should be used at each intersection. However, if as was done in the sites investigated during this research effort, several of these devices can be used without much delay to traffic if the data collection is well-coordinated ahead of time. Well-coordinated field testing should not take much more than a standard project-level FWD-testing.

FWD

The FWD is the main structural strength test indicator for TxDOT. The deflections from the FWD can help identify the weaknesses in the pavement layers. Also, the backcalculated moduli can be used in the structural design for rehabilitation. At each site, the following steps are recommended:

1. Walk the site and identify the most representative lane(s) for testing (usually lane that is most distressed). In most cases, the inner of outer wheelpaths are good representation of the most distressed area of the pavement.
2. Test several hundred feet before and and/or after the intersection also as a comparative tool. Compare the pavement response close to the intersection with those away from it to determine whether the structural problem is wide spread throughout the roadway or is

localized in the vicinity of the intersection. 25 to 30 FWD points are sufficient for proper diagnoses.

3. Document all surface distresses in the comment sections of the FWD tests and monitor the temperature of the hot mix asphalt.
4. Follow typical project level FWD testing setup with four drops at each point.

The structural condition index (SCI), base curvature index (BCI) and backcalculated moduli of the layers are used as input in the expert system to determine the structural weakness in underlying layer(s). SCI is defined as the difference in the first two deflections (d_0-d_1) and BCI is defined as the difference in the second and third deflections (d_1-d_2).

GPR

The GPR is another device that assists in identifying subsurface conditions of flexible pavements rapidly. GPR provides information especially with regards to the uniformity of the thickness of the hot mix asphalt and base. This can be used to verify design thickness and identify rutting in the base and or subgrade layer. Although the GPR thickness profile is not used as direct input in the expert system, a representative value of the layer thickness is an input into the tool. The data collection for GPR is easy and requires no traffic control. The data collected from the GPR can be reduced with ColorMap and PaveCheck. PaveCheck allows users to simultaneously view GPR and FWD data, as well as a video of the site.

PSPA

The PSPA is another nondestructive device that is available to TxDOT and can be used to test layer moduli of the top layer. Similar to the FWD the PSPA can be used to check and verify the design modulus of the top layer. The same data collection process described for the FWD can be followed. The data reduction process for the PSPA is straightforward and the layer moduli can be easily obtained.

Trenching and Coring

Trenching and coring although destructive provide absolute verification of the structure of the pavement. Both methods require traffic control and patching once complete. Trenching operation provides viable information especially when structural rutting is suspect. Figure 8.2 is taken from the TxDOT Pavement Design Manual for illustration purposes. Since many District staff do not favor trenching especially at intersections, coring can be used as an alternative. Based on our experience, collecting five cores across the lane is quite valuable. The recommended locations of the cores are: inner edge, inside wheel path, center, outside wheel path, and outer edge. Figure 8.3 depicts a set of cores that were collected from one of the sites investigated under the project. The cores show the variation in thickness from the center core to the cores taken along the wheelpaths. 4-inch diameter cores are sufficient to identify any potential structural distress. It is recommended that a set of five cores be taken close to the intersection and another set away from the intersection. The two sets of cores can be used to determine whether the distress is localized at the intersection or is extended further in the roadway.

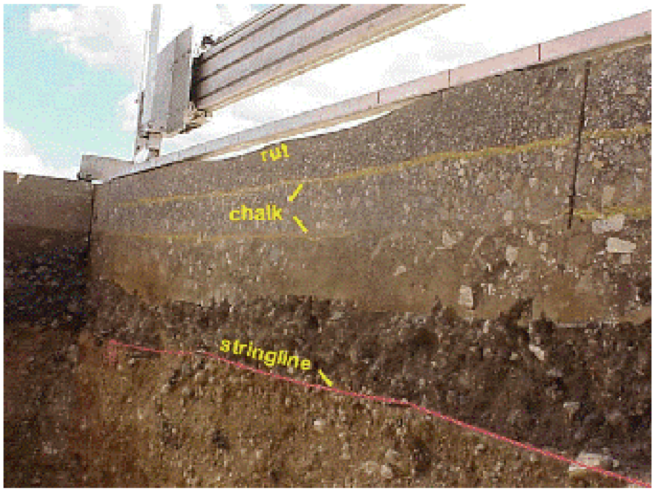


Figure 8.2 - Trench as part of a Forensic study to Identify Structural Rutting.

Figure 8.3 - Coring operation for a Core Profile across a Pavement Section.

<u>*DCP*</u>

DCP serves as a good verification tool for estimating layer thicknesses and moduli. Two sets of DCP testing should be conducted, one set away from the intersection and one set close to the intersection. A set of at least three tests (in the center and two wheelpaths) are recommended. The layer thicknesses and moduli can be used in the expert system as a screening tool to determine structural weakness in underlying layer.

SPECIAL CONSIDERATIONS FOR STRUCTURAL REMEDIATION

Intersections are subjected to slow standing traffic (typically less than 10 mph) and thus exerting heavier loads, opened to traffic much earlier than other part of the roadway to minimize impact on local businesses and motorists, subjected to engine fluid drippings while in queue or poor drainage, increase in temperature due to heat exhausts, and excess loading volume from cross flow of traffic. These effects collectively suggest that asphalt pavements at intersections need to be designed and constructed differently than the mainline pavement.

While intersections can exhibit some of the same distresses as the rest of the roadway, the prevailing distresses are rutting, cracking, shoving and bleeding. Therefore, special attention needs to be given to the material selection, mix design, and construction. Below are some of the special considerations to build better intersections.

Material Selection

Asphalt binder selection – Since the Superpave Performance Grade asphalt binder specifications is based on selecting binder based on climate, higher temperature grade should be selected at intersections. When intersections are subjected to stopping due to signalizations or stop signs, the binder should be increased by two grades. This will address the concerns with slower standing traffic and heat exhausts while in queue. In areas where traffic slows down but not necessarily stops as often, such as at yield signs or partial signage (ex. Stop sings in cross-direction only), the binder should increase by one grade. For example, if PG 64 is not working then use PG 70 and PG 76 for intersections.

Aggregates selection – the aggregate selected needs to be able to handle higher load carrying capacity and thereby handling a high degree of stone-to-stone interlock. Figure 8.4 illustrates the concept. The better quality aggregates will provide better resistance to shear. Therefore, consideration to shape, texture, absorption and aggregate crushing potential should be considered. For example, both coarse and fine aggregates should be angular to provide interlock and resist shear (Instability Rutting). Alternatively, stabilization or treatment of the materials should be considered.

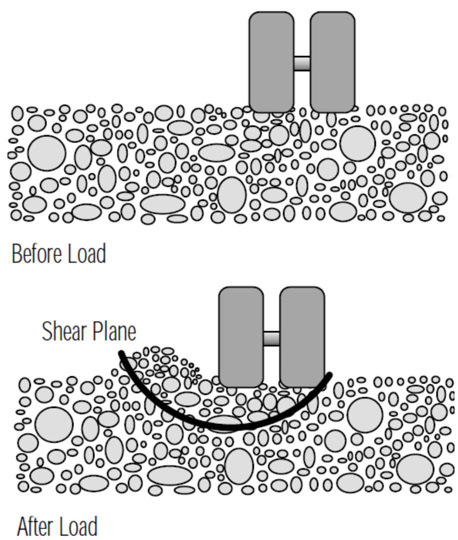


Figure 8.4 - Illustration of Instability Rutting.

Design Considerations

Mix Stiffness – The modulus of hot mix is highly impacted by the stiffness of the mix. Figure 8.5 demonstrates the viscoelastic property of HMA based on the dynamic modulus test. The dynamic modulus test is a preferred fundamental property for HMA, the viscoelastic modulus of the HMA with respect to frequency reveals the magnitude of change in the stiffness. For example, the dynamic modulus is around 600 ksi at typical design frequency of 10 Hz (vehicular speed of 60 mph). However, at intersections the frequency is close to 1 Hz (speed of 6 mph) the dynamic modulus is reduced to 290 ksi. Mixes that resist rutting at posted traffic speeds do not perform well at intersections (slow traffic or standing traffic). Stiffer mixes not only address

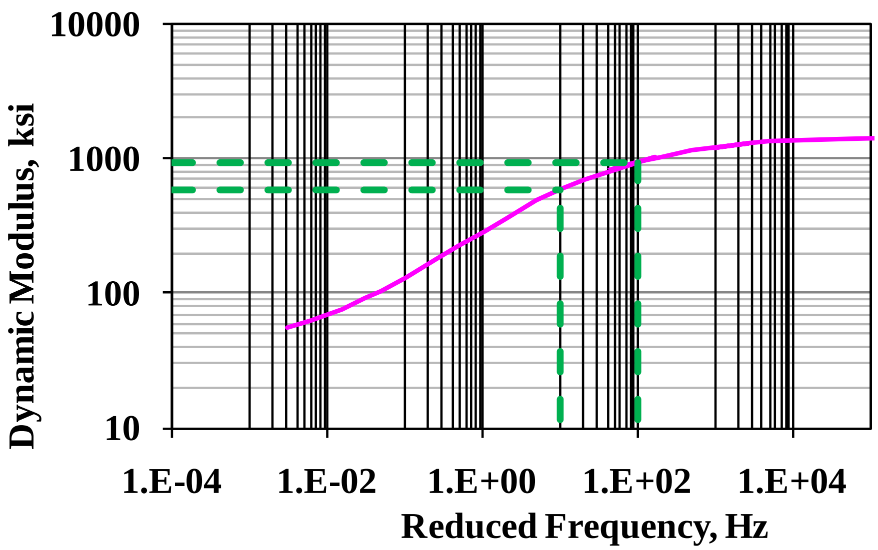


Figure 8.5 - Example of Dynamic Modulus Test Results a.k.a. Master Curve.

slow traffic but other loading schemes at intersections such as braking, accelerating, and turning of heavy loads. Stone-Mastix Asphalt (SMA) mixes are great perfomers at intersections because of high dynamic modulus values at low frequency levels.

Mix Voids-in-Mineral-Aggregate (VMA) – Quality control of the voids becomes even more important at intersections. Mixes with low VMAs are sensitive to relatively small changes in total fluids and can easily lead to rutting and shoving if there is an increase in amount of fluids. On the other end, mixes with high VMA can result in excess binder that causes excess coating of the aggregate. This allows the aggregate to reorient under heavy loading and in turn result in shoving, rutting and bleeding. To remedy this, the designer might desire to increase the target air voids from 4% to 5% or even 5.5%. Also, the inspector should ensure that the plant mix is produced at a tighter tolerance than usually acceptable at high speed pavement section.

Thickness – The main concern with thickness is that intersections require heavy loads, and it becomes necessary to ensure that foundation is sound and that the heavier loading capacity is considered. For existng layer that do not have the appropriate thickness and load carrying capacity it is recommended to remove and replace them. Patching or overlaying the structure will only result in reoccurance of the distress and is not a solution.

Construction Consideration

Quality, Quantity and Time – By the nature of intersections only small quantities of mix is required. Also, minimal constuction time is desired since it has to be opened to traffic as fast as possible to minimze disruption to local businesses. Therfore, there is little time for making changes and the process control must be tight to ensure the mix design is met.

Density – For the superpave mixes or new generation mixes compaction is critical and extra effort is necessary to achieve the desired density.

Cost Effectiveness – One of the sticking points of constructing an intersection is the reluctance of contactors and transportation agencies to work on a small volume project. That is why there are not many agencies that have special provisions for intersections. However, several solutions can be implemeted to sidestep this limitation. One solution is clustering several intersection jobs into a single project. If the intersections are closely spaced, the logical approach is to improve the mix of the entire length of roadway. Let the intersection design dominate the design of the open road as well. This might suggest a higher unit cost at the beginning but will improve the relative performance and reduce the life cycle cost.

CHAPTER NINE – SUMMARY AND CONCLUSIONS

The goal of this project was to understand the mechanisms of intersection pavement failures and to determine the best practices to minimize the failures at existing intersections. The outcome of this project should help to reduce the frequency of maintenance needed at rural intersections. This project also determined how the mechanisms causing the failures at intersections can be mitigated through design and construction modifications. The outcome is an expert system that suggests solutions that can be readily and economically carried out considering type of potential or actual damage at the intersections.

The literature review described the characteristics and mechanisms of the most common types of distresses of asphalt pavements, and covered promising remediation strategies for such problems at different layers of the structure. Such remediation strategies were gathered from research and specifications by several organizations and state agencies throughout the United States and worldwide. Life cycle cost analysis as per the FHWA methodology was also described.

The matrices that links probable distresses and the appropriate remediation resourced from the literature review were created. The matrices aimed to correct distresses by proposing low-cost alternatives that would perform at their best on low volume roads in an effort to avoid common high-cost alternatives. The matrices provided cases where certain remediation is appropriate, likely or might be appropriate, not appropriate and finally not a candidate to solve the identified predominant distress.

One of the major treatment selection factors missed by highway agencies is on considering the different types of rutting separately. Rutting source may be from different layers. The different types of rutting require different types of remediation. The matrices created contains the different types of rutting (surface, instability, and structural) taking into consideration that they come from different sources and thereby should be remedied differently.

Questionnaires were developed and distributed to all Texas Districts. The questionnaires served the following purpose:

- To document the extent of the excessive distress at their intersections,
- To locate the districts that perceive they can benefit from the outcome of this study,
- To identify the current solutions typically used to remedy this problem,
- To document the perceived performance of their intersections after remediation, and

- To solicit projects that can be incorporated in this study.

Interviews were also carried out with several TxDOT district personnel from construction, design, maintenance and area offices.

The research information gathered was incorporated into an easy-to-use online expert system. The system was created to incorporate the knowledge gained as a knowledge base for the selection of remediation strategies. The expert system represents a systematic implementation of the matrix of solutions, which was intended to guide users throughout the process of identifying the proper remediation methods for flexible pavements at intersections and to perform the Life Cycle Cost Analysis (LCCA) to obtain the most economical alternatives.

A thorough explanation of the forensic investigation and the utility of the expert system was presented. Finally, the expert system was used to evaluate several intersections in various districts across Texas after having identified the source of the problem for the selection of a remediation strategy. The result based on LCCA for short term and long term solutions were presented for each intersection.

Also developed is an online guidebook that can be used by TxDOT personnel. An electronic version of the guide provides detailed information to TxDOT personnel in the field. The information is separated into four components: a) common distresses, b) common remediation strategies, c) protocol for data collection, and d) remediation strategies for common distresses.

The product of this study can be useful to TxDOT personnel. New and inexperienced engineers can utilize the knowledge base of the expert system to assist them in decision making. Field personnel can also use this guideline to help them in identifying distress and severity levels. To best disseminate the knowledge to TxDOT District Personnel and refine the tools based on feedback several training sessions should be scheduled.

In addition a pilot implementation study should be carried out to put into practice the process developed under this research study to identify its benefit to TXDOT maintenance and rehabilitation programs.

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APPENDIX A - QUESTIONNAIRE

Questionnaire for TxDOT Research Project 0-5566
Strategies to Improve and Preserve Flexible Pavement at Intersections

Many rural intersections originally constructed with thin untreated flexible base and hot mix or a two-course surface treatment experience severe pushing, shoving and rutting. These failures cause an extremely rough surface that can cause damage to small vehicles and potentially cause motorists to lose control of their vehicle. Pavement sections constructed with the same materials adjacent to the intersection usually perform adequately until the approach (approximately 150 ft in advance) of the intersection and in the intersection itself when the failures become apparent.

TxDOT has initiated a new project to understand the mechanisms of intersection pavement failures and determine the best practices to minimize the failures at existing intersection pavements. The outcome of this project should reduce the frequency of maintenance needed at rural intersections. This project would also determine how the mechanisms causing the surface failures at intersections can be mitigated through design and construction modifications.

Please help us to identify the intersections in your district that can be used for this project by answering the following questions.

TxDOT Research Project TX-0-5566
Distress Questionnaire

District Name:________________________ **Contact Person: ________________________________**

(1) Do your pavements experience distress at the intersections of low volume roads? (Yes / No)

(2) If yes, what percentage of the intersections experiences any type of distress? _______________%

(3) Approximately what percentages of distressed intersections experience the following distress severity? (*total for the three categories should be 100%*)

Low Severity (___%) Medium Severity (____%) High Severity (___%)

(4) What distress types are common at your intersections on low volume roads? (*check all that apply*)

☐Rutting, ☐Shoving, ☐Cracking, ☐Pushing, ☐Other ____

(5) If ***rutting*** is an issue at intersections, please select: (*check all that apply*)

a) Probable cause:

☐Inadequate structures - specify (ex. weak subgrade)_______________________________________

☐Construction quality - please specify (ex. site preparation)__________________________________

☐Traffic - please specify (ex volume, slow moving, channeled)_______________________________

☐Environmental condition - please specify (ex. moisture, temperature)_________________________

☐Inadequate drainage____

☐Subgrade type - please specify (ex. clayey, sandy)____

☐Other____

(6) If ***shoving*** is an issue at intersections, please select: (*check all that apply*)

a) Probable cause:

☐Inadequate structures - specify (ex. weak subgrade)_______________________________________

☐Construction quality - please specify (ex. site preparation)__________________________________

☐Traffic - please specify (ex volume, slow moving, channeled)_______________________________

☐Environmental condition - please specify (ex. moisture, temperature)_________________________

☐Subgrade type - please specify (ex. clayey, sandy)____

☐Other____

(7) If ***cracking*** is an issue at intersections, please select: (*check all that apply*)

a) Probable cause:
☐Inadequate structures - specify (ex. weak subgrade)________________________________
☐Construction quality - please specify (ex. site preparation)__________________________
☐Traffic - please specify (ex volume, slow moving, channeled)_________________________
☐Environmental condition - please specify (ex. moisture, temperature)__________________
☐Subgrade type - please specify (ex. clayey, sandy)__________________________________
☐Other____

(8) If ***pushing*** is an issue at intersections, please select: (*check all that apply*)
a) Probable cause:
☐Inadequate structures - specify (ex. weak subgrade)________________________________
☐Construction quality - please specify (ex. site preparation)__________________________
☐Traffic - please specify (ex volume, slow moving, channeled)_________________________
☐Environmental condition - please specify (ex. moisture, temperature)__________________
☐Subgrade type - please specify (ex. clayey, sandy)__________________________________
☐Other____

(9) (***Other***) ________________________ is an issue at intersections, please select: (*check all that apply*)
a) Probable cause:
☐Inadequate structures - specify (ex. weak subgrade)________________________________
☐Construction quality - please specify (ex. site preparation)__________________________
☐Traffic - please specify (ex volume, slow moving, channeled)_________________________
☐Environmental condition - please specify (ex. moisture, temperature)__________________
☐Subgrade type - please specify (ex. clayey, sandy)__________________________________
☐Other____

TxDOT Research Project TX-0-5566
Distress Questionnaire

(10) Please fill the table below regarding solutions you typically use to remedy each distress and provide typical performance life of each remedy.

Distress	Current solutions you typically use to remedy this problem.	Performance of the remediation
Rutting	□ Hot Mix Overlay, □ Concrete Overlay (White Topping and Bonded PCC) □ Preservation (ex. Chip Seal) □ Rehabilitation (ex. Mill & Fill) □ Reconstruction □ Full Depth Reclamation □ Other ____________________	□ Less than 1 year □ 1 to 3 years □ 3 to 10 years □ More than 10 years
Shoving	□ Hot Mix Overlay, □ Concrete Overlay (White Topping and Bonded PCC) □ Preservation (ex. Chip Seal) □ Rehabilitation (ex. Mill & Fill) □ Reconstruction □ Full Depth Reclamation □ Other ____________________	□ Less than 1 year □ 1 to 3 years □ 3 to 10 years □ More than 10 years
Cracking	□ Hot Mix Overlay, □ Concrete Overlay (White Topping and Bonded PCC) □ Preservation (ex. Chip Seal) □ Rehabilitation (ex. Mill & Fill) □ Reconstruction □ Full Depth Reclamation □ Other ____________________	□ Less than 1 year □ 1 to 3 years □ 3 to 10 years □ More than 10 years
Pushing	□ Hot Mix Overlay, □ Concrete Overlay (White Topping and Bonded PCC) □ Preservation (ex. Chip Seal) □ Rehabilitation (ex. Mill & Fill) □ Reconstruction □ Full Depth Reclamation □ Other ____________________	□ Less than 1 year □ 1 to 3 years □ 3 to 10 years □ More than 10 years
Others (specify) ____________________	□ Hot Mix Overlay, □ Concrete Overlay (White Topping and Bonded PCC) □ Preservation (ex. Chip Seal) □ Rehabilitation (ex. Mill & Fill) □ Reconstruction □ Full Depth Reclamation □ Other ____________________	□ Less than 1 year □ 1 to 3 years □ 3 to 10 years □ More than 10 years

(12) Do you mind if we contact you for further information? (Yes / No)

If you do not mind, please provide the following:

Telephone number: ______________________ Email: ____

APPENDIX B – SUMMARY OF CAUSES OF DISTRESS AND REMEDIATION STRATEGIES FOR EACH DISTRICT

Table B1 – Summary of Causes of Rutting for each District

Districts	Inadequate Structures	Const. Quality	Traffic	Environ. Conditions	Inadequate Drainage	Subgrade Type	Other
Abilene	X		X				
Atlanta	X		X	X		X	
Brownwood			X				X
Bryan							
Ft. Worth	X		X				
Ft. Worth2	X		X				
Ft. Worth3	X		X				X
Houston	X	X	X	X	X	X	
Lubbock	X	X	X	X	X		
Lubbock2	X	X	X	X		X	
Lubbock3	X	X	X	X	X	X	
Lufkin							
Odessa							
Paris	X						
Pharr			X				
San Antonio			X		X		X

Table B2 – Summary of Causes of Shoving for each District

Districts	Inadequate Structures	Const. Quality	Traffic	Environ. Conditions	Inadequate Drainage	Subgrade Type	Other
Abilene	X		X				
Atlanta							
Brownwood			X				X
Bryan	X		X	X		X	
Ft. Worth							
Ft. Worth2			X	X			
Ft. Worth3			X				X
Houston		X	X	X			
Lubbock		X	X	X			
Lubbock2	X		X	X		X	
Lubbock3	X	X	X	X	X	X	X
Lufkin							
Odessa			X				
Paris	X						
Pharr							
San Antonio			X			X	X

Table B3 – Summary of Causes of Cracking for each District

Districts	Inadequate Structures	Const. Quality	Traffic	Environ. Conditions	Inadequate Drainage	Subgrade Type	Other
Abilene	X		X				
Atlanta	X		X			X	
Brownwood			X				X
Bryan	X			X		X	
Ft. Worth							
Ft. Worth2				X			
Ft. Worth3	X			X		X	
Houston	X					X	
Lubbock	X	X	X				
Lubbock2			X	X		X	
Lubbock3	X		X	X	X	X	X
Lufkin	X						
Odessa							
Paris	X						
Pharr							
San Antonio			X	X		X	X

Table B4 – Summary of Causes of Pushing for each District

Districts	Inadequate Structures	Const. Quality	Traffic	Environ. Conditions	Inadequate Drainage	Subgrade Type	Other
Abilene							
Atlanta							
Brownwood		X					X
Bryan	X			X		X	
Ft. Worth							
Ft. Worth2	X			X			
Ft. Worth3	X		X			X	
Houston		X	X	X			
Lubbock			X	X			
Lubbock2	X	X	X	X		X	
Lubbock3	X	X	X	X	X	X	X
Lufkin							
Odessa			X				
Paris	X						
Pharr			X				
San Antonio	X		X	X		X	X

Table B5 – Summary of Causes of Other Distresses for each District

Districts	Inadequate Structures	Const. Quality	Traffic	Environ. Conditions	Inadequate Drainage	Subgrade Type	Other
Abilene							
Atlanta			X				
Brownwood							
Bryan			X				
Ft. Worth							
Ft. Worth2							
Ft. Worth3				X			
Houston							
Lubbock							
Lubbock2							
Lubbock3	X		X	X	X	X	X
Lufkin							
Odessa							
Paris							
Pharr							
San Antonio			X				

Table B6 – Summary of Remediation Strategies for Rutting

Districts	Hot Mix Blade Overlay	Concrete Overlay	Preser.	Rehab.	Reconst.	Full Depth Reclamation	Other
Abilene	X			X		X	
Atlanta				X			X
Brownwood							X
Bryan							
Ft. Worth	X					X	
Ft. Worth2	X			X			
Ft. Worth3	X			X			
Houston	X			X	X		
Lubbock	X		X	X	X	X	X
Lubbock2			X	X			
Lubbock3				X			X
Lufkin				X			
Odessa							
Paris	X				X		
Pharr	X						X
San Antonio				X	X	X	

Table B7 – Summary of Remediation Strategies for Shoving

Districts	Hot Mix Blade Overlay	Concrete Overlay	Preser.	Rehab.	Reconst.	Full Depth Reclamation	Other
Abilene	X			X		X	
Atlanta				X	X	X	
Brownwood							X
Bryan						X	
Ft. Worth							
Ft. Worth2	X			X			
Ft. Worth3				X			
Houston	X			X	X		
Lubbock				X		X	X
Lubbock2			X	X		X	
Lubbock3						X	X
Lufkin				X			
Odessa				X			
Paris	X				X		
Pharr							
San Antonio				X	X	X	

Table B8 – Summary of Remediation Strategies for Cracking

Districts	Hot Mix Blade Overlay	Concrete Overlay	Preser.	Rehab.	Reconst.	Full Depth Reclamation	Other
Abilene	X		X	X		X	
Atlanta			X	X			X
Brownwood							X
Bryan							X
Ft. Worth							
Ft. Worth2	X		X				
Ft. Worth3			X				X
Houston	X		X	X	X		
Lubbock			X			X	X
Lubbock2			X				X
Lubbock3			X				X
Lufkin			X				
Odessa							
Paris	X				X	X	
Pharr							
San Antonio			X			X	X

Table B9 – Summary of Remediation Strategies for Pushing

Districts	Hot Mix Blade Overlay	Concrete Overlay	Preser.	Rehab.	Reconst.	Full Depth Reclamation	Other
Abilene							
Atlanta				X	X	X	
Brownwood							X
Bryan						X	
Ft. Worth							
Ft. Worth2	X			X			
Ft. Worth3				X			
Houston	X			X	X		
Lubbock	X			X		X	X
Lubbock2				X		X	
Lubbock3							X
Lufkin				X			
Odessa				X			
Paris	X				X	X	
Pharr	X						X
San Antonio				X	X	X	X

Table B10 – Summary of Remediation Strategies for Other Distresses

Districts	Hot Mix Blade Overlay	Concrete Overlay	Preser.	Rehab.	Reconst.	Full Depth Reclamation	Other
Abilene							
Atlanta					X	X	
Brownwood							
Bryan	X						
Ft. Worth							
Ft. Worth2							
Ft. Worth3							
Houston							
Lubbock							
Lubbock2							
Lubbock3				X			X
Lufkin							
Odessa							
Paris							
Pharr							
San Antonio							

APPENDIX C - QUESTIONNAIRE FOR THE DISTRCIT INTERVIEW

TxDOT Research Project TX-0-5566
Strategies to Improve and Preserve Flexible Pavement at Intersections
Distress Interview

District name: Date:

Purpose of Interview: Many rural intersections originally constructed with thin untreated flexible base and hot mix or a two-course surface treatment experience severe distress. This research project seeks to understand the mechanisms of intersection pavement failures and determine the best practices to minimize the failures at existing pavement intersections.

The outcome of this project should help to reduce the frequency of maintenance needed at rural intersections. This project would also determine how the mechanisms causing the surface failures at intersections can be mitigated through design and construction modifications.

The information gathered from this research will be used to develop an expert system. An Expert System is a tool used to guide in the design process and provide an easy means for disseminating the knowledge and expertise of specific guidelines and practices to pavement managers and designers across the state. This tool was selected based on the following (among other reasons):

- More than one solution to a problem,
- Expert experiences can be available to everyone, and
- More design consistency across the districts

The following are questions that we thought are appropriate for this interview. Tracy Crumby, the project PD, is helping to coordinate this interview process. This interview will be in a group format to allow for discussion and consensus. The idea is to interview a group from each district that represents the expertise of that district. These questions are provided to you in advance as a means of preparation for the interview so that you are aware of the type of question that will be asked. Thank you in advance for you participation and support of this project.

A. Distress Identification

1. What is low volume traffic in your perception (how many ESALS)?
2. What percent of roads is considered rural in your District/area?
3. Do you have a count on the number of intersection in the District/area?
4. Are intersection treated differently than the remaining part of the road?
    a. Distress identification to repair
    b. Is the condition of the road better 150 ft away from the intersection?
5. What are typical or common distress types found at intersections in your District/area?
    a. Description of each distress type.
    b. Level or severity of a distress.
    c. What are the most probable causes of each type of distress?
    d. Which layer(s) of pavement structure are most probably contributing to distress?
    e. Do you give any consideration to the drainage at intersections?
    f. What preliminary information do you gather for determining the best remediation strategies?
        i. The type and volume of traffic.
        ii. The location of stop signs.
        iii. The depth, extent and shape of the rutted section.
        iv. The speed limit of the roads leading to the intersection.
        v. The best estimate of the pavement layers' thickness and type.

B. Remediation Strategies

1. What are typical remediation strategies (Maintenance, Rehabilitation, Reconstruction) you consider?
    a. Description of each remediation process and unit cost associated with each process.
    b. Probable feasibility of each remediation strategy to solve each type of distress identified.
    c. Effectiveness: short-term (a band aid), intermediate (1 to 3 years), long term (3 to 7 years).
    d. What additional information do you gather for properly designing and constructing each remediation strategy?
        i. Coring and sampling.
        ii. Performing nondestructive testing with FWD and/or GPR.
        iii. Conducting laboratory tests.
        iv. Performing structural design for the new intersection.
        v. Performing life-cycle cost analysis.

2. How do you select materials for each remediation and layer?
    a. Hot Mix Asphalt.
    b. Type of base and/or treatment (use less than 2% additive) or stabilization (more than 2% additive) if necessary.
        i. When do you use base without treatment of stabilization?
        ii. When and how do you decide on treatment or stabilization?
            1. What type of additive to use for a given base?
            2. How to decide on additive concentration?

c. When and how to improve subgrade?
    i. When to use subgrade without treatment of stabilization?
    ii. When and how to decide on treatment or stabilization?
        1. What type of additive to use for a given subgrade?
        2. How to decide on additive concentration?
d. How do you go about selecting the appropriate drainage system?

C. Construction Practices

1. What are the construction practices for each remediation method?
    a. Site preparation.
    b. Construction practices.
    c. Time and scheduling of repairs at intersections.

What type of quality control to implement for each remediation method?

D. Decision Making

1. How is the decision making process in your district or area office in terms of selecting candidates for maintenance and rehabilitation?
    a. How much or what information is gathered to select the maintenance or rehabilitation method?
    b. Is life cycle cost analysis used in the decision/selection process?
    c. What is more important in your decision making, cost or expected life?
2. What is the available budget range for maintenance and rehabilitation for rural road intersections?

E. Remediation Strategies for Common Distress Indicators

Table 1 shows the results from the national and international literature search and the preliminary condition survey that was sent to all districts. Based on your experience Please fill out Table 2 (as a group).

Table A1 - Remediation Strategies for Common Distress Indicators

Flexible Pavement Treatment Selection Matrix

Distress \ Treatment			Maintenance								Rehabilitation										
											HMA Surfacing					PCC		Deep Repairs			
			Microsurfacing	Fog Seal	Crack Seal	Sand Seal *	Slurry Seal *	Ultra Thin Wearing Coarse	Chip Seals	Surface Treatment	Hot in Place Recycling	Cold in Place Recycling	HMA & RAP Overlay	Hot Mix Overlay	HMA & Recycled Asphalt Shingles (RAS) Overlay	PCC Overlay (Thick)	Ultra-Thin Whitetopping *	Full Depth Reclamation	Roller Compacted Concrete (Base)	Stabilization	Moistute Control
Asphalt Layer	Surface Rutting	< 3 / 8 in	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	×	×	×
Asphalt Layer	Surface Rutting	3 / 8 - 1 in	●	○	⦿	⦿	⦿	○	⦿	⦿	⦿	⦿	⦿	⦿	⦿	●		●	×	×	×
Asphalt Layer	Surface Rutting	> 1 in	⦿	○	○	○	○	○	○	○	⦿	⦿	⦿	○	⦿	●		●	×	×	×
Asphalt Layer	Instability Rutting	Low	×	×	×	×	×	×	×	×	○	○	○	⦿	○	●		●	×	×	×
Asphalt Layer	Instability Rutting	Moderate	×	×	×	×	×	×	×	×	○	○	○	⦿	○	●		●	×	×	×
Asphalt Layer	Instability Rutting	High	×	×	×	×	×	×	×	×	○	○	○	⦿	○	●		●	×	×	×
Asphalt Layer	Shoving		×	×	×	×	×	×	×	×	○	○	○	⦿	○			●	×	×	×
Asphalt Layer	Fatigue Cracking	Low	●	⦿	●	●	○	●	●	●	●	●	●	●	●			●	×	×	×
Asphalt Layer	Fatigue Cracking	Moderate	⦿	○	⦿	⦿	○	⦿	●	⦿	●	●	●	●	●			●	×	×	×
Asphalt Layer	Fatigue Cracking	High	○	○	○	○	○	○	○	○	⦿	●	●	⦿	●			⦿	×	×	×
Base	Structural Rutting	Low	×	×	×	×	×	×	×	×	○	○	○	⦿	○		○	●		●	
Base	Structural Rutting	Moderate	×	×	×	×	×	×	×	×	○	⦿	⦿	⦿	⦿		○	●		●	
Base	Structural Rutting	High	×	×	×	×	×	×	×	×	○	○	○	○	○		○	●		●	
Sub-grade	Moisture Intrusion		×	×	×	×	×	×	×	×						×	×	●	×	●	●
Sub-grade	Structural Rutting		×	×	×	×	×	×	×	×						×	×	●	×	●	●

● Appropriate
⦿ May Be Appropriate
○ Not Appropriate
× Not a Candidate
* No TxDOT specifications

APPENDIX D - RESULTS OF THE QUESTIONNAIRE FOR THE DISTRCIT INTERVIEW

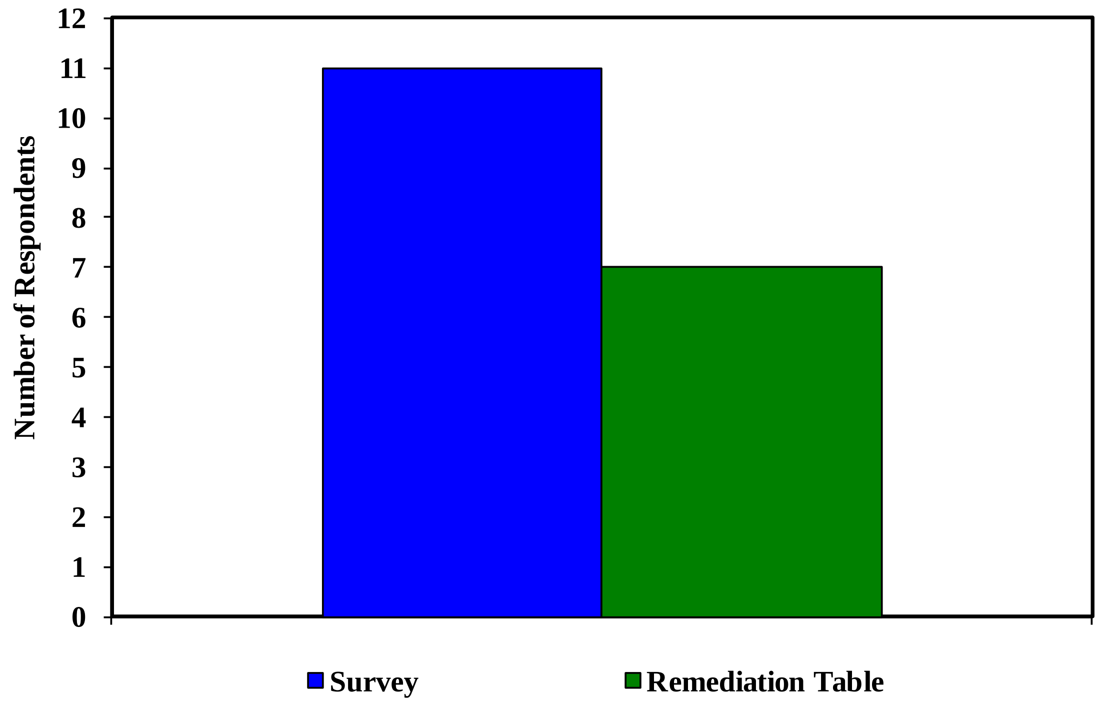


Figure D1 – Number of Respondents from the State.

Table – D1- Perception of Low Volume Traffic in the District.

District	ESAL	ADT
Abilene	<300,000	<500
Atlanta	<1500,000	
Bryan	<500,000	<800
Laredo	<500,000	-
Lubbock*	-	250-500
Houston	<500,000	

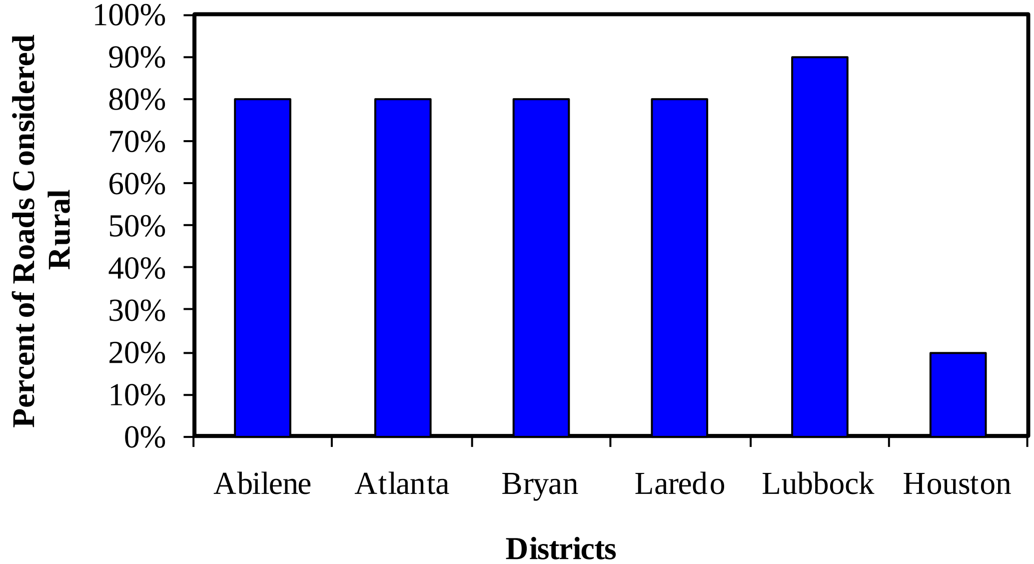


Figure D2 - Percent of Roads is Considered Rural in Districts

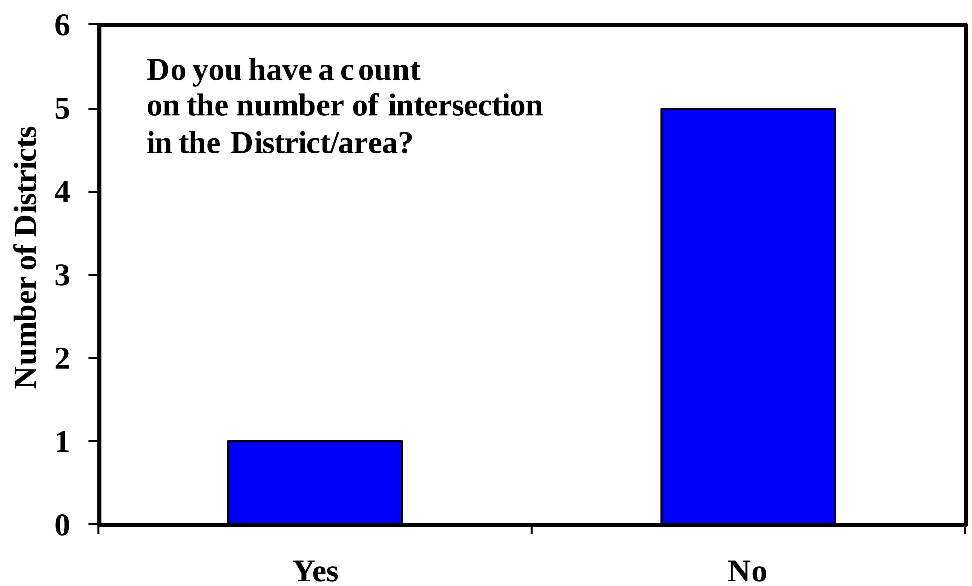


Figure D3 – Results of Whether the Districts Have a Count on the number of intersection in the District

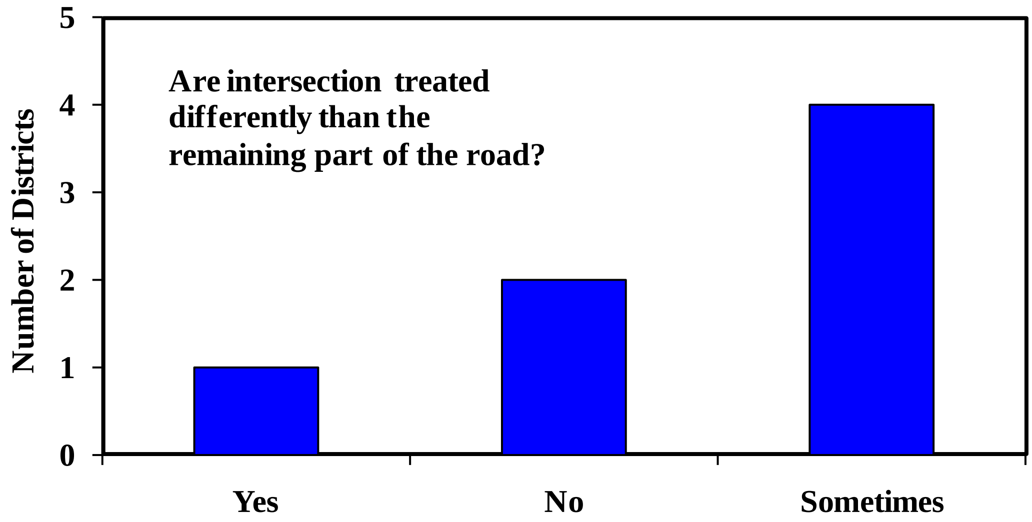


Figure D4 – Results of Whether Intersections are Treated Differently Than the Remaining Part of the Road?

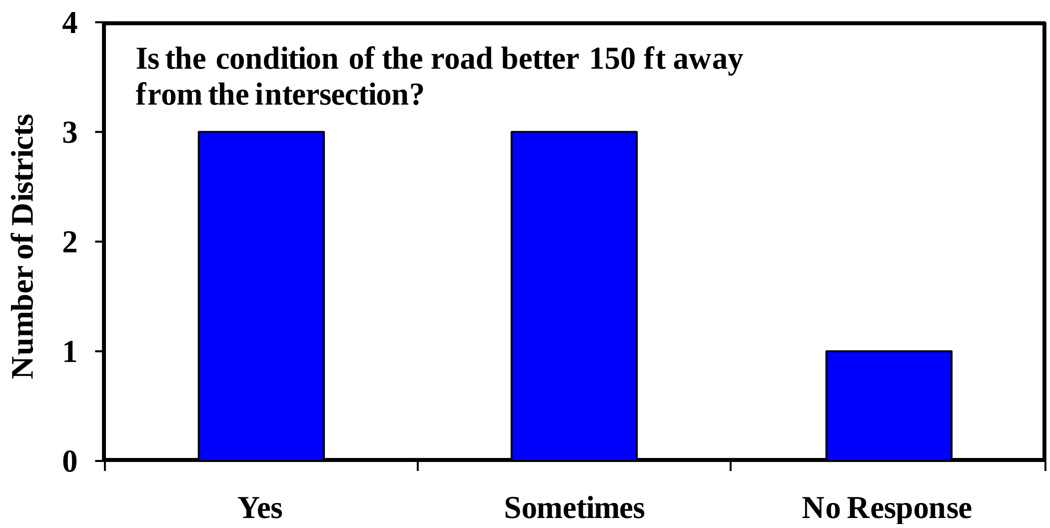


Figure D5 – Results of Whether Road Condition are Better Away From the Intersection

Table D2 – Common Distress Found at Intersections

Distress	Frequency of Responses
Alligator Cracking	7
Block Cracking	1
Flushing	3
Raveling	2
Pushing	2
Rutting	12
Shoving	5

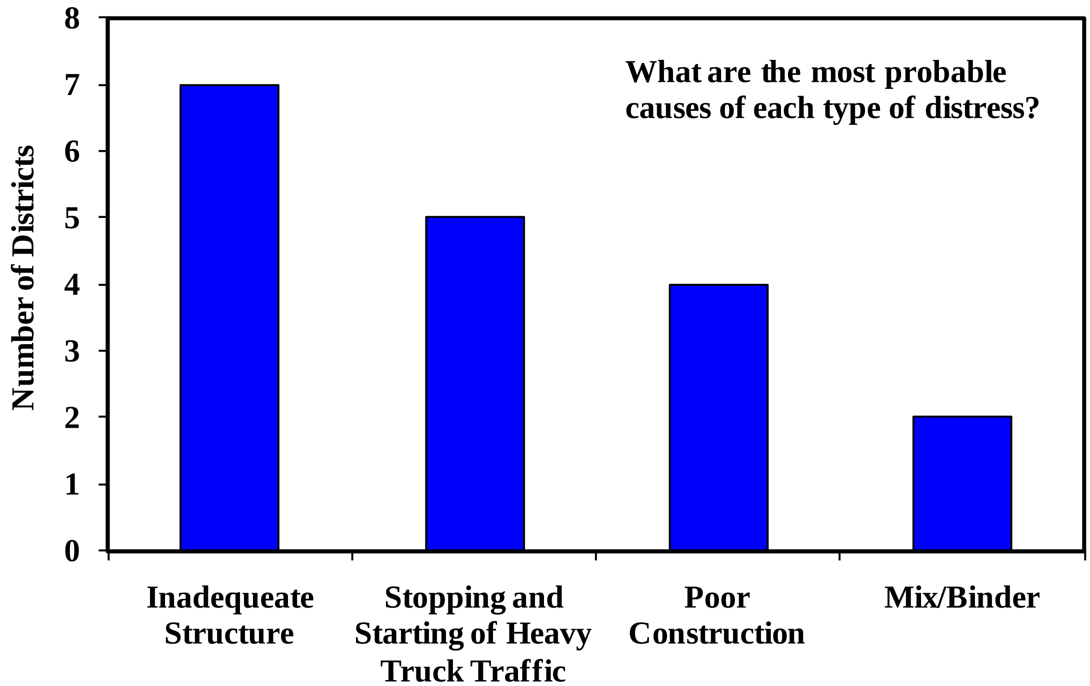


Figure D6 – Results of the Most Probable Causes of Distress

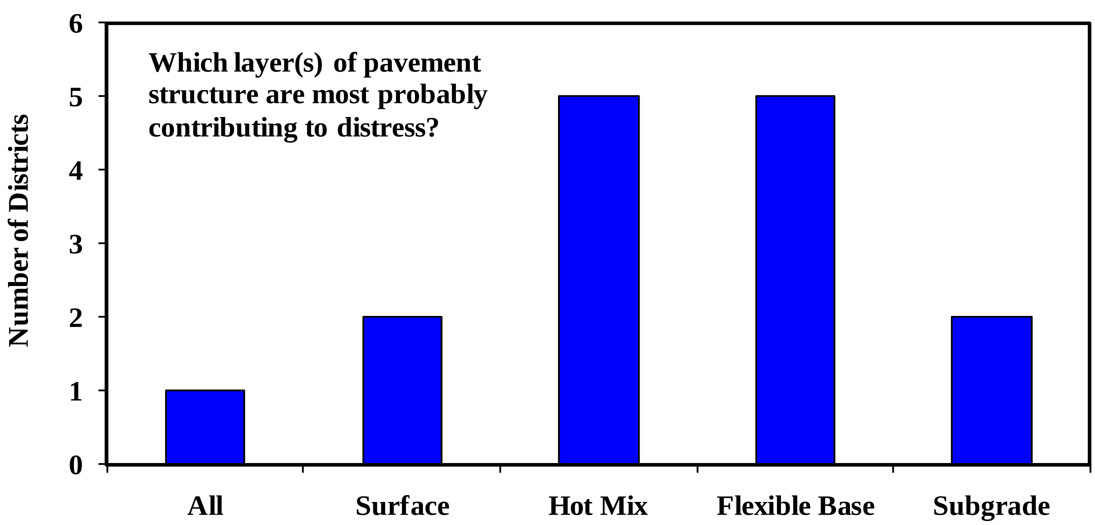


Figure D7 -Results of Pavement Layer That Most Probably Contributes to Distress

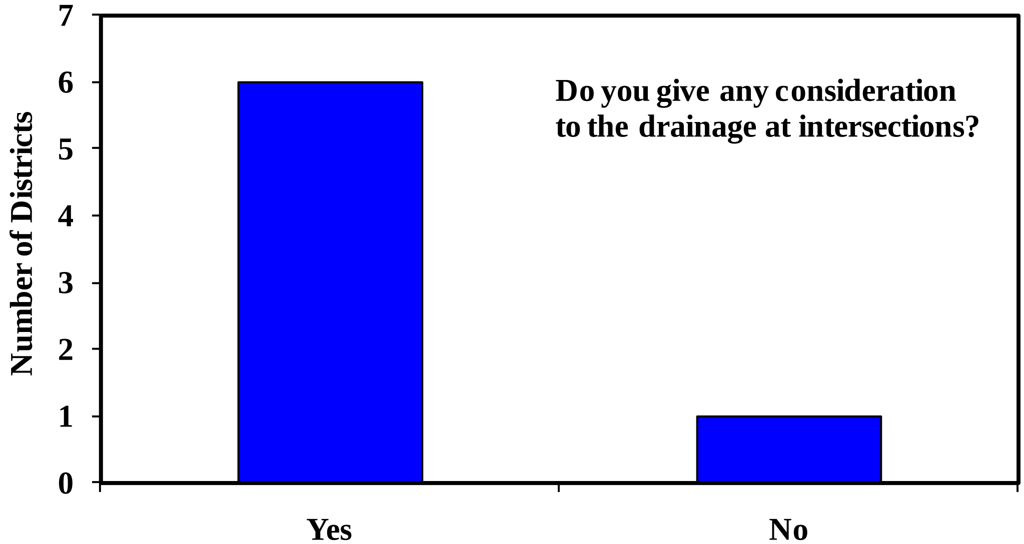


Figure D8 – Results Showing If Drainage is Considered at Intersections

Table D3 – Type of Preliminary Information used for selecting best Remediation Strategies

District	The type and volume of traffic	The location of stop signs	The depth, extent and shape of the rutted section	The speed limit of the roads leading to the intersection	The best estimate of the pavement layers' thickness and type
Abilene	Yes	Yes	Yes	Yes	Yes
Atlanta	Yes	No	Yes	Yes	Yes[1]
Bryan	Yes	No	Yes	Yes	Yes
Laredo	Yes[3]	Yes[2,4]	Yes[5]	Yes	Yes[6]
Lubbock	Yes[7]	Yes[8]	Yes[9]	Yes[10]	Yes[11]
Houston	Yes[12]	Yes[13]	Yes[14]	Yes[15]	Yes[16]

1. In some cases.
2. If possible install signs that indicate the presence of stop.
3. And cross traffic especially truck traffic.
4. Where the intersection is at…to see if the problem is continual throughout the stretch or not.
5. Review existing pavement structure and whether it was stabilized or not.
6. (1)Review old set of plans and generally core to determine typical sections, (2) Check with maintenance section for repair history/problems at location.
7. Low heavy loads.
8. Buy the sign crew field book.
9. Whole intersection.
10. 55MPH.
11. Hot Mix 2 in CMHB.
12. We do all of the following by having cores and traffic analysis done.

Table D4 - Typical Remediation Strategies that are Considered.

Stabilize
Bomag and use cement to set them up and sealcoat
Consider Full Depth Repair good long term solution but very costly
Milling good short term solution and cheap
Overlay intermediate solution and not too costly
Blade Level
Spot Seal

Table D5 - Remediation Process and Unit Cost Associated with Each Process

Mill and Inlay, $13/SY
HMAC @ $70/ton;
Full Depth repair at $35/sy
We have not been letting intersection work separately from roadway work when an intersection needs repair. Normally if the intersection work is split out we replace it with concrete pavement. The last intersection we let- January 2009 through maintenance let for approx. $353,000. Twelve inches CPCD pavement were used with 4" asphalt bond breaker. The roadway, US 57 is approx. 60 ft. wide and 150 ft. was constructed on approaches. Our sections generally fill in rutting with cold mix for temporary repair, or they mill alligator cracking off and then overlay with cold mix.
Add cement to caliches at 5% cost,
Shave or Mill Blade Level, Cost- Shoot a 30% rate of asphalt and cover with rock

Table D6 – Additional Information Gathered for Design and Construction

District	Coring and sampling	Performing nondestructive testing with FWD and/or GPR	Conducting laboratory tests	Performing structural design for the new intersection	Performing life-cycle cost analysis
Abilene	Yes	Yes	Yes	Yes	
Atlanta	Yes	Yes	Yes	Yes	No
Bryan	Yes	Yes	Yes	Yes	Yes
Laredo	Yes	Yes[1]	Yes[2]	Yes[3]	Yes[4]
Lubbock	Yes	Yes	Yes	No	No
Paris	Yes	-	Yes	-	-

1. Generally FWD.
2. DCP, Tri-Axle.
3. FPS 19.
4. Remaining life analysis from TTI.

Table D7 - Selection of Hot Mix for Pavement Remediation

District	Description
Abilene	Traffic Values or Adjacent Roadway
Atlanta	District experience
Bryan	Usually dense graded
Laredo	On sections with high truck traffic causing showing on the wheelpaths, provide PG 76-22 binder and provide thicker asphalt layer
Lubbock	Ask the AE

Table D8 - Selection of Base and/or Treatment for Pavement Remediation

District	When do you use base without treatment of stabilization	When and how do you decide on treatment or stabilization	When and how do you decide on treatment or stabilization	When and how do you decide on treatment or stabilization	Specifications
Abilene	Typically not for remediation and will use some for intersection construction	Weak Base	Typically Cement or Fly-Ash for limestone base	Prior experience	Fly-Ash or Cement Stabilized Base (5-6%)
Bryan	Not for an intersection	-	Cement	We design below 4% so as not too rigid; We run TEX 120E and Moisture Susceptibility	Dependent upon size of needed repair and needed expediency
Laredo	High sulfate content on the subgrade	-	Depending on the PI of the Base course	PI is indicator as to whether to use lime or cement - use pavement manual guidelines	-
Lubbock	Low volume	-	Cement or Asphalt for Black Base	-	If necessary caliches & black base
Paris	When section is thick enough, expansive subgrade	-	Cement for Sandstone	-	Depending on Plastic Index

Table D8 – Decision of How and When to Improve the Subgrade

District	When to use subgrade without treatment of stabilization	When and how to decide on treatment or stabilization	When and how to decide on treatment or stabilization	When and how do you decide on treatment or stabilization
Abilene	Historical performance	Wet or high P.I.	Lime or Cement	Lab (Tex 120/121)
Laredo	The existing pavement structure will be evaluated (FWD, DCP, Trench for Triaxial, FPS 19 analysis), High sulfate content on the subgrade	PI's and sulfate PPM determined	Type depends of the PI of the subgrade PI < 15 cement, PI > 15 Lime or Cement	Tex 120-E or 121-E
Lubbock	Based on pavement thickness above subgrade		Availability	By lab testing
Paris	Plastic Index		PI	PH level

Table D9 – Process of Selecting the Appropriate Drainage System

District	Responses
Abilene	No set method
Atlanta	Determine what is in place, Row limitations, detailed layout with elevations when C&G involved or special ditch grades involved
Laredo	Research to determine what the problem is, review, visit the field to see conditions, run hydraulic calculations
Lubbock	Keep water as far from road as you can & over size your culvert

Table D10 – Practices Employed for Site Preparation

Frequency	Answer
2	As outlined in spec. book
1	An existing is usually minima, maybe removal of debris build-up
1	Visit site with maintenance and area office personnel. Gather old set of plans and review how existing was designed, obtain traffic data existing and proposed (TP&P), collect pavement data, and run FPS 19 program
1	Ask the Area Engineer
1	Clean area, clear drainage path

Table D11 - Practices Employed for Construction Practices

Frequency	Answer
2	As outlined in spec. book
1	When under traffic a normal expedited method (milling, cut, restore, etc.) relative to the material type
1	Ask the Area Engineer

Table D12 - Practices Employed for Scheduling Repairs

Frequency	Answer
1	Depends on materials and intersection use, ex. School traffic
1	Off peak
1	Varies
1	Ask the Area Engineer
1	Warm weather
1	Depend what method is used, short term is immediately and then a permanent solution will be planned on yearly plan

Table D13 – Quality Control measures to Implement Remediation Methods.

Frequency	Answer
1	Same as applied to a roadway section relative to material type
1	Experience
1	Ask the Area Engineer
1	As outlined in spec. book
1	None
1	All jobs inspected and have to be in compliance with TxDOT specifications and testing requirements

Table D14 – Decision Making Process in Terms of Selecting Candidates for Maintenance and Rehabilitation.

Frequency	Answer
1	Need
1	Field review by District and Area Staff and then meet to rank project for the district
1	Don’t know
1	If we are still only talking intersection, typically maintenance supervisor or area engineer
1	PMIS scores along with the Area Engineers input are used to determine candidate projects
1	If it is broken we fix it in the maintenance the only time an intersection is rebuilt is on a construction project and that is where they cut the cost of the project down. Most of them or poor no money are though put in it. It is just an intersection

Table D15 – Type of Information Gathered to Select the Maintenance or Rehabilitation Method

Frequency	Answer
1	Depends on the situation
1	Varies, visual to FWD and below surface investigation
1	See A.5.f or B.1.d depending on severity
1	Don’t know
1	Visual rating, profiling and other scoring systems are done on the facility
1	The problem is identified, site visits are made, alternative pavement designs are evaluated, and based on analysis the location is schedule for repair when budget allows
1	Following information is gather traffic volume, amount of trucks, extend of damage and testing of road pavement

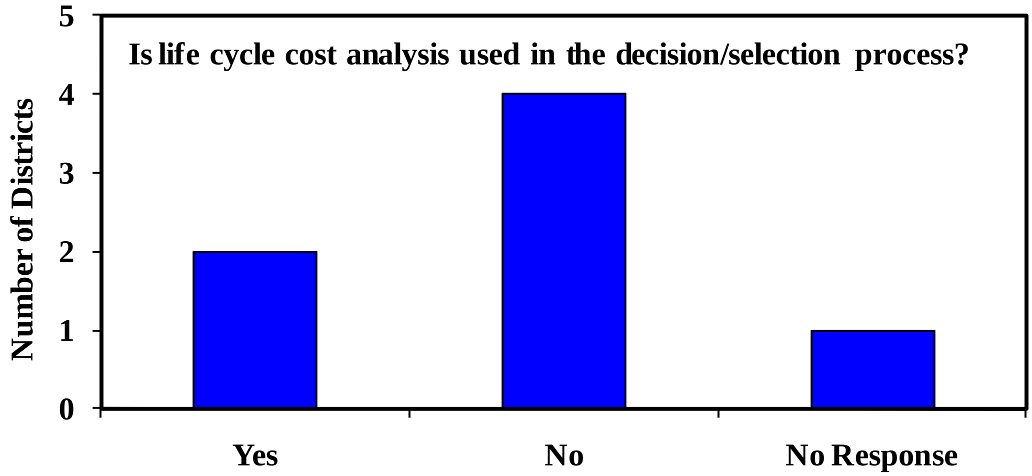


Figure D9 – Results of whether Life Cycle Cost Analysis is Used in the Decision/Selection Process

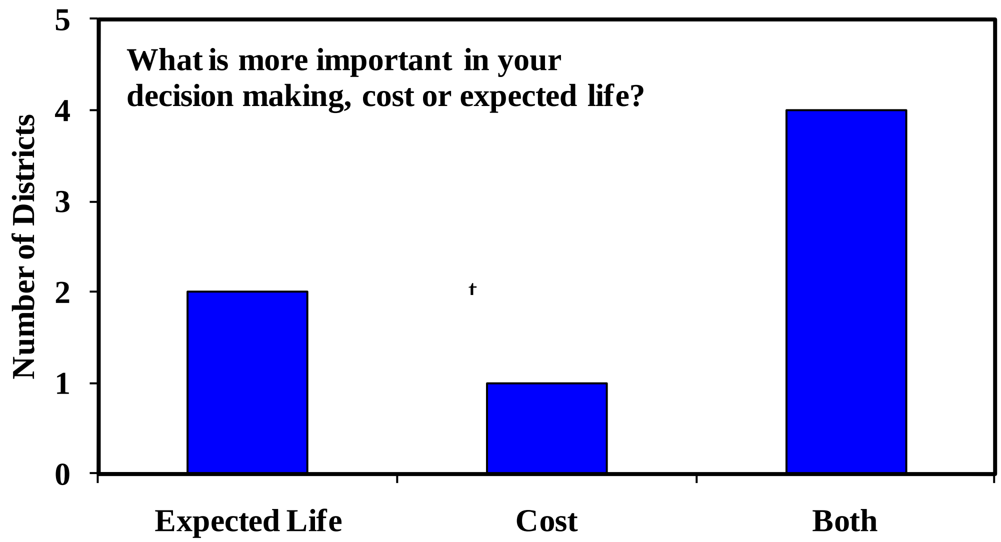


Figure D10 - Cost or Expected Life in Decision Making

Table D12 – Budget Range for Maintenance and Rehabilitation

Frequency	Answer
1	We have no set amount
1	Up to $25,000/intersection
1	Depends on need vs. total funds available to District for maintenance and rehabilitation. Do not set aside just for intersections
1	Small
1	The budget is not split out specifically for intersections especially in the rural areas. In general under Maintenance (contracts and internal work) our District receives approx. $7.0 M/yr, under Construction approx. $8.0 M for PM type projects and $28.0 M/yr (FY 10-12 avg.)
1	It varies per county, maintenance section and situation

Table D13 – Flexible Pavement Treatment Selection Options (Bryan District)

Flexible Pavement Treatment Selection Matrix

Distress \ Treatment			Maintenance								Rehabilitation										
											HMA Surfacing					PCC		Deep Repairs			
			Microsurfacing	Fog Seal	Crack Seal	Sand Seal*	Slurry Seal*	Ultra Thin Wearing Coarse	Chip Seals	Surface Treatment	Hot in Place	Cold in Place	HMA & RAP Overlay	Hot Mix Overlay	HMA & Recycled Asphalt Shingles (RAS) Overlay	PCC Overlay (Thick)	Ultra-Thin Whitetopping	Full Depth Reclamation	Roller Compacted Concrete (Base)	Stabilization	Moistute Control
Asphalt Layer	Surface Rutting	< 3 / 8 in	●	×	×	DO NOT USE	DO NOT USE	●	●	WE CONSIDER THIS THE SAME AS CHIP	DO NOT USE	DO NOT USE	CONSIDER HMA OVERLAY	●	CONSIDER HMA OVERLAY	DO NOT USE	DO NOT USE	×	HAVE NOT USED	×	HAVE NOT USED ANY THAT WORK
		3 / 8 - 1 in	×	×	×			⦿	×					●				×		×	
		> 1 in	×	×	×			×	×					●				⦿		⦿	
	Instability Rutting	Low	×	×	×			×	×					●				×		×	
		Moderate	×	×	×			×	×					●				⦿		⦿	
		High	×	×	×			×	×					●				⦿		⦿	
	Shoving		×	×	×			×	×					⦿				⦿		⦿	
	Fatigue Cracking	Low	×	×	●			●	●					●				×		×	
		Moderate	×	×	⦿			⦿	●					●				⦿		⦿	
		High	×	×	×			×	×					●				⦿		⦿	
Base	Structural Rutting	Low	×	×	×			⦿	⦿					⦿				×		×	
		Moderate	×	×	×			×	×					⦿				⦿		⦿	
		High	×	×	×			×	×					⦿				●		●	
Sub-grade	Moisture Intrusion		×	×	×			×	●					×				⦿		⦿	
	Structural Rutting		×	×	×			×	×					×				⦿		⦿	

● Appropriate
⦿ May Be Appropriate
○ Not Appropriate
× Not a Candidate

Drainage problems might require new design and reconstruction
It is recommended that whitetopping be placed over an AC layer with a thickness of at least 75 mm (3 in.) after milling.

Table D14 – Flexible Pavement Treatment Selection Options (Atlanta District)

Flexible Pavement Treatment Selection Matrix																								
			Maintenance								Rehabilitation													
											HMA Surfacing					PCC		Deep Repairs						
Distress		Treatment	Microsurfacing	Fog Seal	Crack Seal	Sand Seal*	Slurry Seal*	Ultra Thin Wearing Coarse	Chip Seals	Surface Treatment	Hot in Place	Cold in Place	HMA & RAP Overlay	Hot Mix Overlay	HMA & Recycled Asphalt Shingles (RAS) Overlay	PCC Overlay (Thick)	Ultra-Thin Whitetopping	Full Depth Reclamation	Roller Compacted Concrete (Base)	Stabilization	Moistute Control	Mill and Inlay	Mill and Profile	Ultra-Thin Bonded Wearing Coarse
Asphalt Layer	Surface Rutting	< 3 / 8 in	●	○	○	●	●	●	⦿	×	●	⦿	●	●	●	●	●	●	×	×	×	●		
		3 / 8 - 1 in	●	○	○	⦿	⦿	○	○	×	⦿	⦿	⦿	⦿	⦿	●	×	●	×	×	×	●		
		> 1 in	⦿	○	○	○	○	○	○	×	⦿	⦿	⦿	○	⦿	●	×	●	×	×	×	●		
	Instability Rutting	Low	⦿	×	×	×	×	×	×	×	○	○	○	⦿	○	●	×	●	×	×	×	●		
		Moderate	⦿	×	×	×	×	×	×	×	○	○	○	⦿	○	●	×	●	×	×	×	●		
		High	×	×	×	×	×	×	×	×	○	○	○	⦿	○	●	×	●	×	×	×	●		
	Shoving		×	×	×	×	×	×	×	×	○	○	○	⦿	○	×	×	●	×	×	×	●	●	
	Fatigue Cracking	Low	○	⦿	⦿	×	×	●	●	●	●	●	●	●	●	⦿	×	●	×	×	×			●
		Moderate	○	○	⦿	×	×	⦿	⦿	⦿	●	●	●	●	●	⦿	×	●	×	×	×			●
		High	×	○	○	×	×	○	⦿	○	⦿	●	●	⦿	●	×	×	●	×	×	×			●
Base	Structural Rutting	Low	×	×	×	×	×	×	×	×	○	⦿	⦿	⦿	⦿	×	×	●	⦿	●	×			
		Moderate	×	×	×	×	×	×	×	×	○	⦿	⦿	⦿	⦿	×	×	●	⦿	●	×			
		High	×	×	×	×	×	×	×	×	○	○	○	○	○	×	×	●	○	●	×			
Sub-grade	Moisture Intrusion		×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	●	×	●	●			
	Structural Rutting		×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	●	×	●	●			

● Appropriate
⦿ May Be Appropriate
○ Not Appropriate
× Not a Candidate

Drainage problems might require new design and reconstruction
It is recommended that whitetopping be placed over an AC layer with a thickness of at least 75 mm (3 in.) after milling.

Table D15 – Flexible Pavement Treatment Selection Options (Laredo District)

Flexible Pavement Treatment Selection Matrix			Maintenance								Rehabilitation: HMA Surfacing					Rehabilitation: PCC		Rehabilitation: Deep Repairs										
Distress		Treatment	Microsurfacing	Fog Seal	Crack Seal	Sand Seal*	Slurry Seal*	Ultra Thin Wearing Coarse	Chip Seals	Surface Treatment	Hot in Place	Cold in Place	HMA & RAP Overlay	Hot Mix Overlay	HMA & Recycled Asphalt Shingles (RAS) Overlay	PCC Overlay (Thick)	Ultra-Thin Whitetopping	Full Depth Reclamation	Roller Compacted Concrete (Base)	Stabilization	Moistute Control	RAP and Cement	Tupe I (Black Base) Gr. AA	Cold Mix Blade - Covel-Up	Mill and Overlay	Concrete Pavement	Thick AC Layer	Thick Flux Bare Layer
Asphalt Layer	Surface Rutting	< 3 / 8 in	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	×	×	×			●	●			
Asphalt Layer	Surface Rutting	3 / 8 - 1 in	⦿	●	⦿	⦿	⦿	⦿	⦿	⦿	⦿	⦿	●	●	⦿	●		●	×	×	×			●	●			
Asphalt Layer	Surface Rutting	> 1 in	○	○	○	○	○	○	○	●	⦿	⦿	⦿	⦿	⦿	●		●	×	×	×			●	●			
Asphalt Layer	Instability Rutting	Low	○	×	×	×	×	×	⦿	○	●	●	●	●	●	●		●	×	×	×			●	●			
Asphalt Layer	Instability Rutting	Moderate	○	×	×	×	×	×	×	×	●	●	⦿	⦿	●	●		●	×	×	×			●	●			
Asphalt Layer	Instability Rutting	High	○	×	×	×	×	×	×	×	⦿	○	○	⦿	⦿	●		●	×	×	×							
Asphalt Layer	Shoving		×	×	×	×	×	×	×	×	○	○	○	⦿	○			●	×	×	×			●	●			
Asphalt Layer	Fatigue Cracking	Low	●	●	●	●	○	○	○	●	●	●	●	●	●			●	×	×	×			●	●			
Asphalt Layer	Fatigue Cracking	Moderate	○	○	○	○	○	⦿	⦿	⦿	⦿	●	●	●	●			⦿	×	×	×			●	●		●	
Asphalt Layer	Fatigue Cracking	High	○	○	○	○	○	○	○	○	⦿	⦿	●	⦿	●			○	×	×	×					●	●	●
Base	Structural Rutting	Low	×	×	×	×	×	×	×	×	×	×	×	×	×		○	●		●								
Base	Structural Rutting	Moderate	×	×	×	×	×	×	×	×	×	×	×	×	×		○	●		●		●	●					●
Base	Structural Rutting	High	×	×	×	×	×	×	×	×	×	×	×	×	×		○	●		●		●	●					●
Sub-grade	Moisture Intrusion		×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	●	×	●	●							
Sub-grade	Structural Rutting		×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	●	×	●	●							

● Appropriate
⦿ May Be Appropriate
○ Not Appropriate
× Not a Candidate

Drainage problems might require new design and reconstruction
It is recommended that whitetopping be placed over an AC layer with a thickness of at least 75 mm (3 in.) after milling.

Table D16 – Flexible Pavement Treatment Selection Options (Abilene District)

Flexible Pavement Treatment Selection Matrix

Distress \ Treatment			Maintenance								Rehabilitation: HMA Surfacing					Rehabilitation: PCC		Rehabilitation: Deep Repairs				
			Microsurfacing	Fog Seal	Crack Seal	Sand Seal*	Slurry Seal*	Ultra Thin Wearing Coarse	Chip Seals	Surface Treatment	Hot in Place	Cold in Place	HMA & RAP Overlay	Hot Mix Overlay	HMA & Recycled Asphalt Shingles (RAS) Overlay	PCC Overlay (Thick)	Ultra-Thin Whitetopping	Full Depth Reclamation	Roller Compacted Concrete (Base)	Stabilization	Moistute Control	Mill and Fill
Asphalt Layer	Surface Rutting	< 3 / 8 in	●	○	○	○	●	●	●	●	●	⦿	●	●		●	●	●		●		⦿
Asphalt Layer	Surface Rutting	3 / 8 - 1 in	●	×	○	○	⦿	⦿	●	●	●	○	●	●		●	⦿	●		●		●
Asphalt Layer	Surface Rutting	> 1 in	⦿	×	×	○	○	○	●	○	●	○	⦿			●	○	●		●		●
Asphalt Layer	Instability Rutting	Low	⦿	×	×	○	●	×	●	×	⦿	⦿	●	●		●	●	●		●		●
Asphalt Layer	Instability Rutting	Moderate	×	×	×	○	⦿	×	●	×	○	○	●	●		●	⦿	●		●		⦿
Asphalt Layer	Instability Rutting	High	×	×	×	○	×	×	○	×	○	○	⦿	⦿		●	○	●		●		○
Asphalt Layer	Shoving		×	×	×	○	×	×	×	×	○	○	×	×		●	⦿	●		●		●
Asphalt Layer	Fatigue Cracking	Low	⦿	×	●	○	×	⦿	●	●	●	⦿	×	×		●		●		●		●
Asphalt Layer	Fatigue Cracking	Moderate	×	×	●	○	×	○	●	●	●	⦿	×	×		●		●		●		⦿
Asphalt Layer	Fatigue Cracking	High	×	○	○	○	×	○	○	○	⦿	○	○	○		●		⦿		●		○
Base	Structural Rutting	Low	×	×	×	○	×	×	×	×	○	×	×	×		●		●		●		○
Base	Structural Rutting	Moderate	×	×	×	○	×	×	×	×	○	×	×	×		⦿		●		●		○
Base	Structural Rutting	High	×	×	×	○	×	×	×	×	○	×	×	×		⦿		●		●		○
Sub-grade	Moisture Intrusion		×	×	×	○	×	×	×	×	○	○	○	○				●		●		○
Sub-grade	Structural Rutting		×	×	×	○	×	×	×	×	○	○	○	○				●		●		○

● Appropriate
⦿ May Be Appropriate
○ Not Appropriate
× Not a Candidate

Drainage problems might require new design and reconstruction
It is recommended that whitetopping be placed over an AC layer with a thickness of at least 75 mm (3 in.) after milling.

APPENDIX E - SUMMARY OF THE DISTRICTS INTERVIEWS

Austin District
Date: April 13, 2009
Attendees: District and Division Personnel

The interview was informal. It was summarized below in the first person from the districts point of view. The focus of this interview was to:

1. ***Understand District practices,***
2. ***Introduce them to the work being developed under this project and***
3. ***Get feedback on any preferences that can be incorporated into the products being developed that would be of benefit to the District.***

Comments on the district issues regarding intersections and pavements in general:
Most of Austin's intersections on FM roads have subgrade issues, typically in the eastern part of the district. These types of roads typically have agricultural traffic exposure. We seal coat and level-ups time after time, but never really take care of the real issue because of monitory constraints.

As I said, a lot of our FM's are getting neglected because the concentration of our money is for metro areas since it is growing rather than the outskirts which is okay out west where we have rock and things are seal coated out there so we don't have that issue, where it has been hitting us hard, for any type of ADT is in east and north, like in eastern counties.

Typically, when we have intersection issues or higher ADT's, you put the wrong mix in the intersection. Where you have seal coats or PFC's, they are raveled out or the shoulders/turn lanes weren't design correctly. Especially when we have a widened section and the main lanes are settled since they have been trafficked for a long time and you have this un-trafficked shoulder build-up, it starts consolidating and you end up with faulting and they do level-ups trying to take care of those issues.

What we've been trying to do especially if is a turning lane with high PI clays, we are starting to use geogrid as the means of trying to stabilized the system and trying to get with a bigger foot printed distributed stress. That way, you do not have a bad faulting and settlement. So we are using geogrid a lot more.

We're a big raveling district and the reason it's because of high absorption in our aggregates and not enough asphalt in the mix. Now we promote more we promote better aggregates and more and better asphalt content.

At intersections where we have an ADT issue, what we'll do is go ahead and do full-depth repair and put in a Type-B.

For high truck ratio, we do bump-up of our binder (ex. From a 64-22 to 72-22) because there's higher number of tucks there.

Another issue we have is our base. In this district, we believed in 18" bases stiff layers where we have not treated the soils very well. So according to Texas Tri-axial you're okay and that was typically dictated around here. The problem now is we have concentrated critical stresses between the base and hot-mix interface, so now we have these growing Type-E layer to protect the base, because they are so thick and all the stresses right there are getting unstable.

Instead of putting stabilized layer they substituted with the thickness of base, so this made the base higher and thicker, this is to try to make it more stable. So we are kind of suffering for that, especially out East.

Comments regarding PMIS:
We are actually working together with maintenance and so I've been working with CTR, helping us put a local database together.

One thing we're trying to do with the condition score is we're having CTR develop a database with the distress score and have all the inputs in there the rutting, the cracking, the failures, everything in there , and you can see what actually changed, is it rutting?, is it cracking?, or what? That way you can see the distress knowing that we can play around the whole section, the full section. It can be localized, so that way we can focus specifically on those areas instead of overlaying the whole section and that way you just can do chip seal, seal coat, specific rather than paying for the whole section.

What we are doing now is we are going to start a list of candidates based on half a mile sections, and we are going to set criteria conditions according to right scores and deterioration rates and generate candidate lists, kind of check on our system.

We have deterioration rate, so we can see the curves along the section, either it‘s been stabilizing and then it's fall out for some reason, and it's sort of declining.

The big picture of ours is to have that PMIS into the data base system, but also to have someone experience with the database and GIS stuff so that I'm giving them all the seal coats and overlays that has ten years and for each section. Now that all that will all be in a local database. We are even including crash data. I'm getting our contract to UT firms to make a soils database, so that way we're going to try to merge all these pavement information, soils information and performance to kind of have all these multiples levels that will help us evaluate our sections better. And the administration is pushing that thought, that's why you get to work closely with the maintenance folks.

The crash data is very crucial now since there have been so many high profile accidents because Austin is growing so much and the urban areas are catching up with the rural section and the road sections are wide open straight up where people are speeding, but then once you get on west it is all curvy and also deep. That is when you get more people crashing without rain, but when it does rain you know then its all pavement. In Austin, we finally have an Austin district transportation safety team, so now not only they look at bad weather but also at utility poles, right of way and all the stuff that can contribute to crashes. So safety will always be category we consider as number 1.

Comments on the research products of this project:
I'll tell you one thing, getting another piece of software is not going to be used, but if you have something like (a summary sheet of distresses and remediation). This is more effective. Unless this tool is built into FPS19 or something like that.

The only software that we use are PMIS, FPS19, or DARWIN if we're doing concrete and PaveCheck which is for GPR, modulus and stuff like that. But something this specific, I would rather a list or summary sheet.

Bryan District
Date: April 14, 2009
Attendees: District Personnel

The interview was informal. It was summarized below in the first person from the districts point of view. The focus of this interview was to:

1. ***Understand District practices,***
2. ***Introduce them to the work being developed under this project and***
3. ***Get feedback on any preferences that can be incorporated into the products being developed that would be of benefit to the District.***

Comments on the district issues regarding intersections and pavements in general:
On rehabilitation projects, the existing pavement is typically cement treated. In intersections it is difficult to stabilize the existing material. Instead of treating, the existing material is excavated and replaced with new base (the depth of treatment plus new base depth which depends on the pavement design and is typically 8"+6" of new base).

One area we have problem is with edges. Maybe put a note in there to look at the turning movements of the traffic through and make sure it's working just as a key for the designer to know. We don't think that we always check for that.

As far as distresses, the major problem in our district is shoving. Also, failures occur just because the seal is torn. We try not to put hot mix on anything though.

Looking at seal coats, we have less than a 1000 ADT, you don't seem to have as much problems with the seal coat. On average we use ADT of 850.

We classify traffic as: 0-400 low, 400-1500 is medium, and above 1500 is higher.

Once traffic is over 800 ADT, we start to see it on the wheel path, just in general down the road from an intersection and for sure after 1000 ADT you can see the wheel path is worn down or flushed up.

The biggest factor is the high trucks volume. We can have a 400 vehicle range, with a high truck volume, a high percentage truck ratio, that will really just really raise that asphalt. That is going to be one of those special conditions.

In this case, we will probably have to fix it for safety and then plan to do a deep repair later just depending on how busy the intersection is.

Comments on the research products of this project:
Based on the presentation, UTEP outlined the two products of the projects, the handy guideline and the expert system, the guideline that shows the maintenance and distress chart was more preferable than another program. We also like this chart because if we did have problems with maintenance and we wanted to look at something it might be good to

have a cost per square yard for each of these and then we can decide which one is more cost effective for us. It would be an asset to put on there an expected life on the repairs. Also it's a good idea that there are diagrams with those pictures. I think if you put that diagram and the pictures would help more.

Comments regarding PMIS:
Historically, the Bryan district uses PMIS and looked at the scores due to failures and ride. The first part is to go through all of the PMIS data, which is broken in half mile sections and we looked at failures in adjacent half mile sections and then generate a list of roads.

Basically there are two parts: a) jobs that had to do with maintenance contracts and b) some to do with construction contracts depending on length and how bad they were. To pick the road to be worked on, the district folks drive the roads and identify the worst to prioritize them. Traditionally, based on the review of the road and the PMIS data, the higher volume roads do not have below 70 score. These roads are reviewed differently for repairs.

Historically, the two main problems are soil and failures. Our soils are highly variable with PIs from 0-80. The soils have a hard time maintaining ride, so we don't focus much on ride, we focus more on making sure they don't have failures. This way our scores are kept up. We have kept up an internal database that shows the individual distresses that affects the score and we have them all plotted from the last ten to twelve years.

We try to focus on the worst problems to fix and maintain them the best way with our budget. We really look at long term because of our bad soils. We feel that just going out and overlaying might fix ride but in six months we lose the ride so it is not the best use of the money. That is why they focus on distresses so that they can bring their scores up and sustain it at least in the short term.

Houston District
Date: April 15, 2009
Attendees: District Personnel

<u>The interview was informal. It was summarized below in the first person from the districts point of view. The focus of this interview was to:</u>

1. ***<u>Understand District practices,</u>***
2. ***<u>Introduce them to the work being developed under this project and</u>***
3. ***<u>Get feedback on any preferences that can be incorporated into the products being developed that would be of benefit to the District.</u>***

Comments on the district issues regarding intersections and pavements in general:
Most of our rural intersections are cement stabilized base with asphalt surfaces. That's pretty much our district policy. Our past history has pretty much demonstrated that we get better performance or better life out of going ahead with concrete even if it's with a little bit of more cost.

Even on the design of intersections, we treat them like the entire roadway. In general, we don't really see a lot more distress at intersections. However, there might be a tighter pattern at intersections. We think that is because we use a very stiff base material to hold the asphalt and we are using higher asphalt content and higher grades asphalt now.

When there is more distress at intersections it is because of construction. Intersection work needs to be rapid due to traffic concerns and many times even holding traffic for 15 minutes gets it backed-up more than we want. So in many cases the rolling patterns might be off, we just roll it out and we are not so sure were following a rolling pattern or we just get something rolled up and get out of the intersection. That is why we try to do more night work when we can.

We also see curb damage at the intersections, but I think we've pretty much addressed that with the new code by beefing up the curb.

For overlay we use high grade asphalt due to the nature of traffic. The distresses are longitudinal cracking and a lot of those are widened after the fact because the capacity of the facility is growing so they add a right turn-lane and for some reason they'll go with different material and or use the same material that does not bond together at the joint. Other cases are we would go for a deeper depth base and water collects underneath and gets trapped from underneath and then we end up with some cracking.

Another issue we have is that our subgrade is terrible from basically sand to high PI.

Comments on the research products of this project:
As far as the product coming out of this project, we don't have a problem with an expert system. We are getting a lot of inexperienced people with the new generation of engineers and most of the time, they go out there and see some cracking and decide to overlay. They do not know if it's a base failure or not. They're not looking any further

then what they see on the surface and that becomes a big issue. But give someone a tool like the expert system, where they can go in and give them an idea of what to look at, and then you start asking questions. That is where I see the utility or advantage of this tool.

We have had several experiences out there where we get calls saying that the pavement shows spalling and we tell them what to do. A year later, they call back and say that we told them wrong. So we finally said, well, you need to send us pictures first, what they were classifying as spalling was probably not spalling. It actually needed to be a full-depth repair. They don't know what cracking is, they don't know, unless you show them. They do not know the different type of rutting that can be out there.

So if you have a tool that say you need to open it up and compare it to a picture of it then have a flowchart on what you do with this distress. We can minimize misdiagnosing the problem and get more life out of our pavement. Therefore, the guideline is also very useful as well, especially for field work.

Comments regarding PMIS:

We go and collect the data and then what we do is overlay a map from map zapper that is color coded and based on each stress type. We also have a condition map, a general condition map of the roadway. The rides data is also included. Then our maintenance section will drive the roads and what they do is take these maps and go and look at them. This is to basically verify them.

Our program has preventative maintenance and rehabilitation money. We have the area maintenance offices give us the worst roads and estimates to fix them. Once we have that information, then we'll go ride theses lanes, independently first. Then we go out there and ride with the engineers again and make the call. If they know a whole bunch of past performances and problems, then they'll go ahead and call us. The pavement group starts getting the cores and if they have any kind of delamination or if it's a base problem or GPR and see if there's water underneath there. Then it calls for some sort of analysis to assess the problem.

In addition, we look at skidded data and we are building that database. A lot of times our traffic bunch, record safety in the districts. We also look at the wet weather accidents report which comes out of traffic.

We repaired several roads with that combination, wet weather accident and the skid. Sometimes maybe the skid, maybe you had a lot of weather accidents but it's not related to skid at all, it could be a design issue.

Atlanta District
Date: April 20, 2009
Attendees: District and Area Personnel

<u>The interview was informal. It was summarized below in the first person from the districts point of view. The focus of this interview was to:</u>

1. ***<u>Understand District practices,</u>***
2. ***<u>Introduce them to the work being developed under this project and</u>***
3. ***<u>Get feedback on any preferences that can be incorporated into the products being developed that would be of benefit to the District.</u>***

Comments on the district issues regarding intersections and pavements in general:
As a District, we feel that we target intersections. We look at the roadway, but the maintenance sections especially, target intersections. However, intersections may be a little bit of a secondary issue.

The problem with intersections is that they are part of the roadway. As problematic areas come-up we take care of it. However, the nature of the beast, one wants to combine several areas together because it works the same. Traffic is also a consideration. So the best solution is to put all in one job and have an intersection rehabilitation project. Most of the rehab is mill and inlay. That's the number one quick and dirty remediation. One of the main concerns is to minimize disruption.

The types of distresses encountered in this district are rutting, loss of seal coat aggregates and weak structure. Our PIs range from zero to 70.

In many cases, pavement designs have never been representative of the amount of traffic on our roads. That is why we end up with concrete intersections around our district.

Thus far with the farm roads and high PI clays in Atlanta, there has not been anything yet that is out there that's going to "free us from that plague" without spending huge amounts of money right away on the pavement structure itself. Many of the solutions so far are not practical.

Comments regarding PMIS:
The process of how we target our sections starts first with pulling a listing of a PMIS score first and especially those that have a condition score less than 70, but we won't necessarily limit to that and we use PMIS as a guide as to where we are having issues and we go out and look at the pavement. We still depend on the maintenance supervisors and the engineers in the district to send in recommendations as to what needs attention. We use PMIS as a first recommendation. We don't use the PMIS generated recommendations since there are so many differences across the state. The materials that we use, have access to, are different, the cost of those materials are different, the weather is different, and the soil is different. There are a lot of variables to account for and PMIS is not there yet and we think that is why we can sit here and say we don't use recommendations of PMIS.

For example, we can have a fairly low score and the roadway doesn't have the traffic to warrant a rehab job. You could have maintenance forces go and perform preparatory-work for chip seal or for seal coat. The seal coat takes care of the issues in PMIS. Then you run through one of the seal coat cycle and you are back up to 95 as far as score.
The PMIS data, the contract picks up in September and then usually finishes in December and at that same time we are out collecting the profile data, you know rut and ride. Maintenance will come in there during the summer just before that starts and seal everything.

Atlanta has had an organized seal coat program for years plus we have a mill and inlay crew that will mill and inlay ACP as needed. Therefore, when the contractors come in to collect the PMIS data, they will never see these cracks or anything. The cracks may redevelop that next cycle, obviously PMIS has no structural number or anything that's representative of what is there.

So unless you can look at maintenance cost to know that it was covered, you won't have any idea that of the distresses. The score may reflect a good condition score of 100, but we may have to go the next year and mill and inlay.

We have to look at that, it may not have a low condition score that hurts us but we know we have a problem so we know that it is costing us. We have to finally breakdown and do something. We can get criticized for it, but we get FWD data to justify what we are doing. That has to be done before we commit the money to it.

Bottom line is that PMIS certainly doesn't take everything into account and that's one of the reasons we have to verify what is in place. It is good to have the information from PMIS, but we have to make the decisions on what to do.

Paris District
Date: April 22, 2009
Attendees: District and Area Personnel

The interview was informal. It was summarized below in the first person from the districts point of view. The focus of this interview was to:

1. ***Understand District practices,***
2. ***Introduce them to the work being developed under this project and***
3. ***Get feedback on any preferences that can be incorporated into the products being developed that would be of benefit to the District.***

Comments on the district issues regarding intersections and pavements in general:
In Paris district the Maintenance Section supervisor and Materials personnel take care of problematic areas on intersection. Budget constraints do not allow for changing the mix for intersection as frequent as might be necessary. Intersection work is small volume so it depends mainly on producers. The producers have to deal with issues such as a transportation problem, storage problem, etc.

The main issue we face at intersections are rutting and shoving. Most of our problems here is a mix issue. The rutting and shoving problems that occur are not necessarily heavy truck volume but mainly heavier truck traffic. The problem is caused by the stop and go process that is inherently performed by these heavy trucks.

As a District, the preference is to construct intersections out of concrete but since the intersection are not primary, lack of funding forces continuous maintenance such as milling and patching. Due to the budget, we are fixing problem areas and improving lane miles. The best way to improve our score is light rehab for our lane miles.

A lot of our rural roads have surface treatment and not hot mix. Most of our problem with the structure on FM road is due to environment such as areas where we have trees and then a lot of cracks can be produced.

Comments on the research products of this project:
For heavy volume roads, if this program that is being developed under research project 0-5566, " ", is able to identify that the problem is a mix problem then the use of other mix designs might be considered more. The only problem that is foreseen is with the producers.

As a district, we would like to see that this program be used to target induced distresses and high volume roads. For low traffic roads, maintenance is doing a good job of addressing the problem. Based on the attendees' opinions, one option that this district favors is the use of white-topping at intersection since full depth concrete is cost prohibitive.

Lubbock District
Date: April 27, 2009
Attendees: District and Area Personnel

The interview was informal. It was summarized below in the first person from the districts point of view. The focus of this interview was to:

1. ***Understand District practices,***
2. ***Introduce them to the work being developed under this project and***
3. ***Get feedback on any preferences that can be incorporated into the products being developed that would be of benefit to the District.***

Comments on the district issues regarding intersections and pavements in general:
Several maintenance supervisors and area engineers were present at the meeting.

Intersections are part of the entire roadway. Our biggest problem here is the freeze and thaw cycles as well as heat. Particularly, in most of our intersections are shelling (loss of aggregate), rather than rutting. It cracks up and starts shelling. Our practice has been to seal it, but it is only sustained for a year and a half at the most. In our experience, intersections have heavier distress than the rest of the roadway?

We use some CMHB and SMA mixes in most cases, rutting is usually handled by level-ups. We have had problems with CMHB. Example: run out of polymer and ended up using whatever was available to finish the job what ends up happening is that the road does last a year before it starts cracking.

We are going by the Hamburg test and in order to prevent rutting we have to lessen the asphalt, we are designing based on 96% density and we should be designing in 96.5%. What ends up happening is that contractors have to compact that mix almost to the point of almost cracking. What it means is that CMHB will probably get 4.1% asphalt and it should be about 4.5% or 4.6%.

When they get to intersections, we're cutting the corner. For example, we had the intersections with some cracks in it, maybe some minor rutting, but they went in there milled it and sealed it and laid the new CMHB in there. Bottom line is, you don't build a 2 million dollar house and put in a piece of chicken wire for a roof. It is going to leak. I don't care how many seal coats you put underneath it, you need some Type D or maybe some B mix or something like that underneath it. I'd rather it rut a little bit than just push up and shove up.

As far as stabilization, I think the ones that are mainly stabilized are the ones that had problems in the past and that the maintenance forces went in and stabilized them. I don't think it's a common practice with newer sections.

The other problem we have is the axle loads. First of all, dairy trucks, those trucks, maneuver trucks or farm trucks are not going to have axels that are positioned or distributed according to specs. They are not equally distributed. Those tires seem like they're going to bust.

No one is going to stop these trucks until the fix their problem. They have to let it go through. And they say well one is not going to hurt. And I think one load can make a big difference, especially if we are going to be ranked. And we've got flexible pavement we have to keep our ditches there vegetated. The water is not going to evaporate through there, and all of a sudden if it rains there's going to be moisture underneath that pavement. All of a sudden you're putting a 150kip pound load on there.

Our PI is decent, between 6 and 20. We design for 80,000 pounds. We also have pretty god bases and we usually stabilize with cement.

Another thing is when you get asphalt at $25000 a transport, and you can say 2 transports on a project, 2 transports are $50000. So were designing everything on a loaner. And then you go through conditions like the Hamburg, but you rather have 0.33mm or one that's 12.5mm. The pavement is so stiff not only it cracks, it shatters. It is like peanut brittle.

In this district the base is going to be carrying our load because we construct with 6 to 8 inches of base plus 2 core surfaces. The base cores are critical here. So I think you guys are on the right thing, saying we got to have a better bases, more base and better structure base.

Abilene District
Date: April 28, 2009
Attendees: District and Area Personnel

The interview was informal. It was summarized below in the first person from the districts point of view. The focus of this interview was to:

1. ***Understand District practices,***
2. ***Introduce them to the work being developed under this project and***
3. ***Get feedback on any preferences that can be incorporated into the products being developed that would be of benefit to the District.***

Comments on the district issues regarding intersections and pavements in general:
On the roadway, we typically use Superpave mixes. At times at intersections, where we knew it's going to be lot of traffic, we transitioned from Superpave over existing base to a full depth hot mix sections. An example will be on a frontage road we are building now, between the exit ramps, we transitioned from a 4in type-D over fly-ash treated base to full depth hot mix section with an 8 in. of type B and under seal and 2 in. of type-D on top. This is because of the high volume of traffic. The same was done to the intersection of FM206 and FM379 where got the concrete approaching the intersections. We put full depth in both directions and only at the intersection. We think with whitetopping from what I see the problems will be fixed more permanently.

The problem with white-topping on rural areas is we typically don't have the asphalt thickness. So you're going to have to dig it out and put asphalt and then white topping. I don't think that's really cost effective, that's why we go for full depth concrete (reinforce concrete). However, that is the only alternative to reinforced concrete (whitetopping).

So as far as treatment, we take care of the rutting problems at the intersections with concrete that will be the top priority and then after that you know some type of full depth hot mix. Actually, concrete is option 1, then ultra-thin whitetopping, then hot mix's. We have used in-place repairs with fly-ash and cement. These will be the next in line after hot mix.

In our district, we mainly have a thick base section with a 2 coarse surface treatment. Most of our road and intersections have that pavement structure. When we start having problems and you know eventually we'll go in with one of these other treatments we've been talking about. Yeah, whether it be that maintenance going in there and trying to stabilized the subgrade or adding some more base material if we need to and then put another surface treatment on it or even taking the base out and put in a new thick hot mix section.

In general, our bases are made of limestone and we are very happy with it.

Comments on the research products of this project:
The use of the product that comes out of the research is for two different groups, you know one from the design stand point (FPS19 check) to see the pavement structure. The other is for the maintenance stand point. From the design stand point, I don't think you know we're really considering intersections at all; the design output gives the exact same structure as the roadway.

I think this tool will be very valuable for our section supervisors because they will be fixing the problems. That is why the maintenance guideline with pictures will come in handy.

One recommendation is to have distresses as a combination because at times it is not mainly one dominant distress. Also as far as remediation, it is also a combination. For example you do level up in a macro-seal or PFC overlay. An overlay by itself might not be appropriate, but a level-up plus a remediation is more practical. This will be a big benefit.

The thing I like is the use of pictures and figures. I do really well with pictures.

Laredo District
Date: April 29, 2009
Attendees: District and Area Personnel

The interview was informal. It was summarized below in the first person from the districts point of view. The focus of this interview was to:

1. ***Understand District practices,***
2. ***Introduce them to the work being developed under this project and***
3. ***Get feedback on any preferences that can be incorporated into the products being developed that would be of benefit to the District.***

Comments on the district issues regarding intersections and pavements in general:
In some of our areas, we are playing catch-up depending on the funding and the money that is available, but we have areas that we have been maintaining with maintenance crews. If we have money we are putting concrete and if you don't then you are buying time.

One part of what we do is we fix intersection as part of the roadway. We don't fix them independently unless we get rutting. In those cases, we use concrete, other than that using something else we never have.

I guess the area where we are at; we are in Laredo. If one follows our truck traffic, we have a large amount of trucks coming through. Say we have any farm roads in our area with rutting from any kind of equipment other than trucks. We have addressed some with cement stabilization on the bottom.

Rutting-out the surfaces is usually due to hot mix and what happens is it shoves it out, pushes it out. Our hot mix is Type D, and we usually have good hard bases (fresh limestone). As we mentioned before, due to our truck traffic through our counties, we get a lot of stop and go problems.

By the same token on US roads that come through here, there was a time when we weren't stabilizing the base and we had the rutting, we went to stiffer flex bases and stiffer hot mixes now you have the cracking. So it is like we went from one extreme to the other. Now with these intersections, we do have the strong structural beneath it but the top is not holding up.

We guess it is more in our area, when you come into these intersections you are slowing down you're going to stop. Yeah it ruts out, you will get a few calls from people, hey there is a rut there and you get that call. At the same time, we shift it over to stabilizing the bases and now you get the cracking and when it gets rain and you have the blow outs versus 70 mph down the interstate with a blowout, that's priority over intersection for me, when you see it that way.

The cracking seems to depend on the weather. It follows the weather in times of drought, you have consistent moisture, it will hold together, once you get drought, it will dry-up on you and you will see the cracks.

I guess it depends on where you put the road in (at what time of year).

As far as drainage, we don't have that problem. We have gone with Type C mix with stiffer binders. I think what the district has done as a whole has gone with a stiffer binders in town and self-dividers out on the highway, but they have addressed it as a I guess in the city limits. The idea is that in urban areas you go with a stiffer binder according to traffic and in rural areas you would go with a softer binder.

Comments regarding PMIS:
We are focusing in on the PMIS scores and attacking that right off the bat either through maintenance contracts or construction. We are definitely using PMIS information to define areas that needs to be fixed. First time we go out and check the roads.

Sometime PMIS will show a section that is falling apart and maybe it will be a fifty foot section and the rest will be good for whatever reason, but it throws up a flag, hey go check this out, and we actually go look at it.

We have done several Superpave designs, regular sieve with stronger binders, concrete pavement and stabilization with lime in most areas. We have done some intersections with lime stabilization and I have done other intersections with cement stabilization.

APPENDIX F - TOPSIS

TOPSIS method

Decision making is a part of our daily lives. In decision science, one of the decision making problems is multi attribute decision making (MADM). MADM is associated with the problems in which alternatives have been predetermined. It means making preference decisions (e.g., evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes (Dashti et al., 2010). TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is an example of MADM. TOPSIS assumes that each design option wants to either be maximized or minimized, so the positive-ideal solution for a criterion that wants to be maximized is the maximum value of all the design options considered. The principle behind TOPSIS is simple. The chosen alternative should be as close to the ideal solution as possible and as far from the negative-ideal solution as possible (Dashti et al., 2010). The ideal solution is formed as a composite of the best performance values exhibited (in the decision matrix) by any alternative for each attribute. The negative-ideal solution is the composite of the worst performance values. This method considers three types of attributes or criteria: a) Qualitative benefit attributes/criteria, b) Quantitative benefit attributes, and c) Cost attributes or criteria.

The algorithm used to determine the solution is presented. As documented in Dashti et al. (2010), two artificial alternatives are hypothesized in this method: a) Ideal alternative: the one which has the best level for all attributes considered and b) Negative ideal alternative: the one which has the worst attribute values. TOPSIS selects the alternative that is the closest to the ideal solution and farthest from negative ideal alternative. TOPSIS assumes that we have m alternatives (options) and n attributes/criteria and we have the score of each option with respect to each criterion.

Let x_{ij} score of option i with respect to criterion j. This result in a matrix $X = (x_{ij})$. This is an m×n matrix. Also, let J be the set of benefit attributes or criteria (more is better) and let J' be the set of negative attributes or criteria (less is better). The steps below outline the algorithm for selection of the best option.

Step 1: Construct normalized decision matrix. This step transforms various attribute dimensions into non-dimensional attributes, which allows comparisons across criteria.

Normalize scores or data as follows:

$r_{ij} = x_{ij} / (\Sigma x^2_{ij})$ for $i = 1, \ldots, m$; $j = 1, \ldots, n$

Step 2: Construct the weighted normalized decision matrix. Assume a set of weights for each criteria:

w_j for $j = 1, \ldots n$.

Multiply each column of the normalized decision matrix by its associated weight. An element of the new matrix is:

$v_{ij} = w_j r_{ij}$

Step 3: Determine the ideal and negative ideal solutions.

Ideal solution.

$A^* = \{ v_1^*, \ldots, v_n^* \}$, where

$v_j^* = \{ max\ (v_{ij})\ if\ j \in J;\ \ min\ (v_{ij})\ if\ \ j \in J' \}$

Negative ideal solution.
$A' = \{ v_1', \ldots, v_n' \},$ where
$v' = \{ min\ (v_{ij})\ if\ j \in J\ ;\ \ max\ (v_{ij})\ if\ \ j \in J' \}$

Step 4: Calculate the separation measures for each alternative. The separation from the ideal alternative is:

$S_i^* = [\, \Sigma (v_j^* - v_{ij})^2 \,]^{½} \qquad \boldsymbol{i} = 1, \ldots, \boldsymbol{m}$

Similarly, the separation from the negative ideal alternative is:

$S'_i = [\, \Sigma (v_j' - v_{ij})^2 \,]^{½} \qquad \boldsymbol{i} = 1, \ldots, \boldsymbol{m}$

Step 5: Calculate the relative closeness to the ideal solution C_i^*

$C_i^* = S'_i / (S_i^* + S'_i)\ , \qquad 0 < C_i^* < 1$

Select the option with C_i^* closest to 1.

APPENDIX G - SUMMARY OF THE CORE RESULTS FROM SH 155 AND SH 49 INTERSECTION

Table G1 – Summary of the Core Log

Road	Core #	Sta. or Dist. From	Direction and Lane	Location in Lane	Core Diameter, in	Depth below Surface		Layer Thickness, in	Dist. of Cores	Description of layer including kind, type, and condition
						From, in	To, in			
SH155 & SH49	1	500' North of intersection (from middle of intersection) Rutting:	SH155 SB North of intersection 3/8" IWP	IWP Center OWP 1/4" OWP	6"	0	5/16"	5/16"	OWP Measurements	Lt. wt. Gr. 4 Seal
						5/16"	1 3/4"	1 7/16"		Ty D Siliceous
						1 3/4"	2 1/4"	1/2"		Seal-left in hole
						2 1/4"	0			IOB
	2	100' from middle of intersection Rutting:	SH155 SB North of intersection 9/16" IWP	IWP Center OWP 1/2" OWP	6"	0	3/8"	3/8"	OWP Measurements	Multiple Lt. wt. Gr. 4 Seals
						3/8"	1 3/4"	1 3/8"		
						1 3/4"	2 5/16"	9/16"		Ty D Limestone
						2 5/16"				Multiple Gr. 3 Slag Seals
										IOB
	3	500' West from middle of intersection Rutting:	SH49 EB West of intersection 1/8" IWP	IWP Center OWP 1/4" OWP	6"	0	1 7/8"	1 7/8"	Center Measurements	Ty D ACP Jones Mill-Voids
						1 7/8"	2 1/8"	1/4		Multiple Seals
						2 1/8"	4 1/4"	2 1/8"		Ty C Limestone-Voids
						4 1/4"				IOB-treated
	4	75' West of middle of intersection Rutting:	SH49 EB West of intersection 1/8" IWP	IWP Center OWP 0 OWP	6"	0	1"	1"	OWP Measurements Longitudinal + Transverse Cracks	Ty D Limestone
						1"	1 3/8"	3/8"		Gr. 3 Seal
						1 3/8"	2 13/16"	1 7/16"		Ty C ACP Slag Hot mix
						2 13/16"	3 1/16"	1/4"		Seal
						3 1/16"				IOB

Table G2 - Core #1 Information for Inner Wheel Path on SH 155 South Bound

Intersection	District	Extraction Date
SH 49 & SH 155	Atlanta	April 20, 2009
Core	# 1 IWP	
Thickness, in	1.9	
Location	SH 155 South bound 500ft north	
Modulus	319 ksi	
Asphalt Content	8.57 %	
Notes		

Gradation:

Size	(gr)
1/2"	0
3/8"	91.3
#4	505.6
#40	627
#100	119.4
#200	5.6
Pan(-200)	7.3

Table G3 - Core #1 Information for Center on SH 155 South Bound

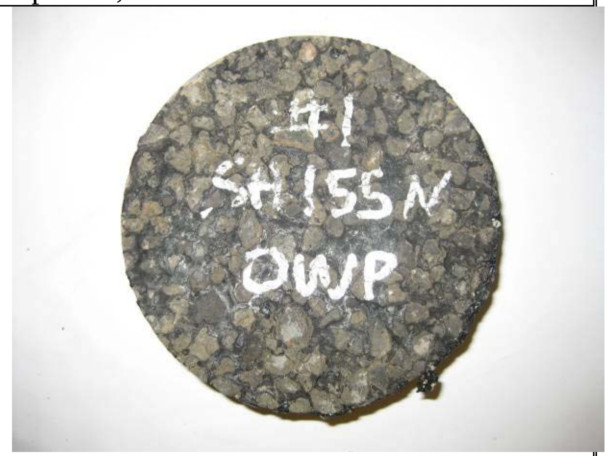
Intersection	**District**	**Extraction Date**
SH 49 & SH 155	Atlanta	April 20, 2009
Core	# 1 Center	
Thickness, in	.5	
Location	SH 155 South bound 500 ft north	
Modulus	215 ksi	
Asphalt Content	7.92 %	
Notes: Specimen broke apart while extracting, only 0.5 in thick slurry seal remained intact.		

Gradation:

Size	(g)
1/2"	2.6
3/8"	135.8
#4	563.5
#40	438.6
#100	158.2
#200	36.2
Pan(-200)	32.1

Table G4 - Core #1 Information for Outer Wheel Path on SH 155 South Bound

Intersection	District	Extraction Date
SH 49 & SH 155	Atlanta	April 20, 2009
Core	# 1 OWP	
Thickness, in	2.5	
Location	SH 155 South bound 500 ft north	
Modulus	256 ksi	
Asphalt Content	6.99 %	



Notes:

- Pieces of the specimen were lost during extraction
- Low to severe fatigue cracking , rutting, loss of aggregate, bleeding, pushing, and block cracking
- FWD data collected at this location

Gradation:

Size	(g)
1/2"	11.5
3/8"	97.8
#4	578.9
#40	545.5
#100	138
#200	5.9
Pan(-200)	6.8

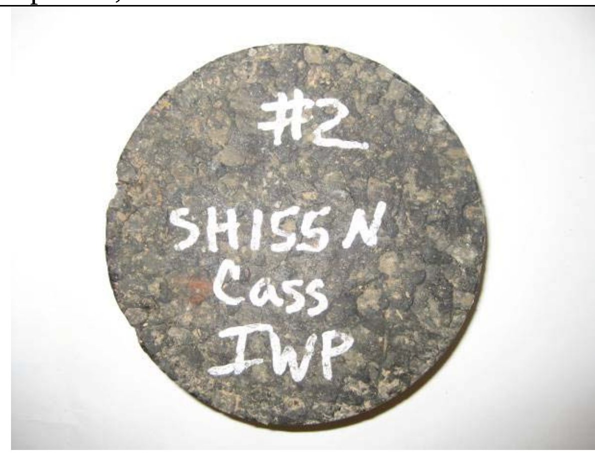
Table G5 - Core #2 Information for Inner Wheel Path on SH 155 South Bound

Intersection	District	Extraction Date
SH 49 & SH 155	Atlanta	April 20, 2009

Core	# 2 IWP
Thickness, in	2.2
Location	SH 155 South bound 100 ft north
Modulus	556 ksi
Asphalt Content	7.6 %

Notes:

- Low to severe fatigue cracking , rutting, loss of aggregate, bleeding, pushing, and block cracking
- FWD data collected at this location

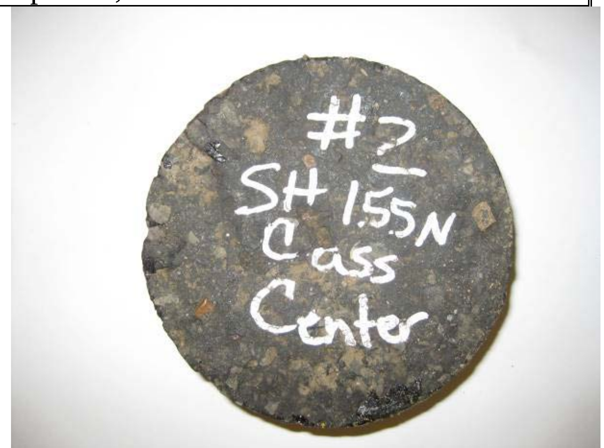


Gradation

Size	(gr)
1/2"	53.9
3/8"	147.4
#4	311
#40	421.8
#100	249.5
#200	111.5
Pan(-200)	46.9

Table G6 - Core #2 Information for Center on SH 155 South Bound

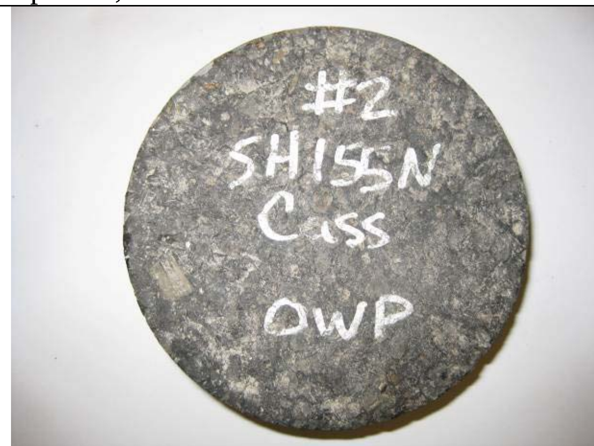
Intersection	**District**	**Extraction Date**
SH 49 & SH 155	Atlanta	April 20, 2009
Core	# 2 Center	
Thickness, in	2.5	
Location	SH 155 South bound 100 ft north	
Modulus	547 ksi	
Asphalt Content	8.46 %	
Notes: Cement detected on the base with Phenolphthalein		



Gradation

Size	**(g)**
1/2"	38.6
3/8"	129
#4	373.5
#40	415.3
#100	179.6
#200	109.9
Pan(-200)	73.9

Table G7 - Core #2 Information for Outer Wheel Path on SH 155 South Bound

Intersection	District	Extraction Date
SH 49 & SH 155	Atlanta	April 20, 2009
Core	# 2 OWP	
Thickness, in	2.4	
Location	SH 155 South bound 100 ft north	
Modulus	581 ksi	
Asphalt Content	7.78 %	
Notes:		
Gradation		

Size	(g)
1/2"	34.8
3/8"	133.8
#4	359.8
#40	425.7
#100	247.2
#200	108.8
Pan(-200)	17.8

Table G8 - Core #3 Information for Inner Wheel Path on SH 49 East Bound

Intersection	District	Extraction Date
SH 49 & SH 155	Atlanta	April 20, 2009
Core	# 3 IWP	
Thickness, in	4.2	
Location	SH 49 Eastbound 500 ft West	
Modulus	671 ksi	
Asphalt Content	4.83 %	

Notes:
- Cement detected on the base with Phenolphthalein
- 42 yards milled by maintenance, severe block cracking and rutting
- T cracking all the way
- 10 in treated base

Gradation

Size	(gr)
1/2"	57.5
3/8"	141
#4	448
#40	679.8
#100	85.5
#200	7.4
Pan(-200)	4.2

Table G9 - Core #3 Information for Center on SH 49 East Bound

<table>
<tr><th>Intersection</th><th>District</th><th>Extraction Date</th></tr>
<tr><td>SH 49 & SH 155</td><td>Atlanta</td><td>April 20, 2009</td></tr>
<tr><td>Core</td><td># 3 Center</td><td rowspan="6"></td></tr>
<tr><td>Thickness, in</td><td>4.2</td></tr>
<tr><td>Location</td><td>SH 49 Eastbound 500 ft West</td></tr>
<tr><td>Modulus</td><td>562 ksi</td></tr>
<tr><td>Asphalt Content</td><td>4.93 %</td></tr>
<tr><td colspan="2">Notes:
• Cement detected on the base with Phenolphthalein
• 42 yards milled by maintenance, severe block cracking and rutting
• T cracking all the way
• 10 in treated base</td></tr>
<tr><td colspan="2">Gradation
<table><tr><th>Size</th><th>(g)</th></tr><tr><td>1/2"</td><td>35.8</td></tr><tr><td>3/8"</td><td>152.7</td></tr><tr><td>#4</td><td>436.2</td></tr><tr><td>#40</td><td>594.1</td></tr><tr><td>#100</td><td>141</td></tr><tr><td>#200</td><td>26</td></tr><tr><td>Pan(-200)</td><td>31.8</td></tr></table></td><td></td></tr>
</table>

Table G10 - Core #3 Information for Outer Wheel Path on SH 49 East Bound

Intersection	**District**	**Extraction Date**
SH 49 & SH 155	Atlanta	April 20, 2009
Core	# 3 OWP	
Thickness, in	4	
Location	SH 49 Eastbound 500 ft West	
Modulus	590 ksi	
Asphalt Content	5.4 %	

Notes:

Cement detected on the base with Phenolphthalein

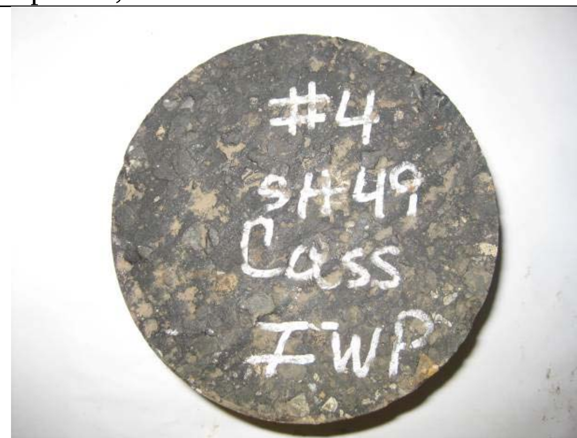
Gradation

Size	(g)
1/2"	28.8
3/8"	122.5
#4	437.8
#40	695.6
#100	100.8
#200	9.8
Pan(-200)	12.8

Table G11 - Core #4 Information for Inner Wheel Path on SH 49 East Bound

Intersection	**District**	**Extraction Date**
SH 49 & SH 155	Atlanta	April 20, 2009
Core	# 4 IWP	
Thickness, in	3.2	
Location	SH 49 Eastbound 75 ft West	
Modulus	398 ksi	
Asphalt Content	7.17 %	

Notes:



Gradation

Size	**(gr)**
1/2"	119.6
3/8"	164.5
#4	310.3
#40	403.9
#100	236.6
#200	128.4
Pan(-200)	27.7

Table G12 - Core #4 Information for Center on SH 49 East Bound

Intersection	District	Extraction Date
SH 49 & SH 155	Atlanta	April 20, 2009
Core	# 4 Center	
Thickness, in	3.1	
Location	SH 49 Eastbound 75 ft West	
Modulus	600 ksi	
Asphalt Content	6.89 %	
Notes:		

Gradation

Size	(g)
1/2"	95.4
3/8"	195.8
#4	326.1
#40	377.6
#100	203.7
#200	109.8
Pan(-200)	75

Table G13 - Core #4 Information for Outer Wheel Path on SH 49 East Bound

Intersection	**District**	**Extraction Date**
SH 49 & SH 155	Atlanta	April 20, 2009
Core	# 4 OWP	
Thickness, in	3.1	
Location	SH 49 Eastbound 75 ft West	
Modulus	571 ksi	
Asphalt Content	6.58 %	
Notes:		
Gradation		

Size	(g)
1/2"	89.6
3/8"	181.6
#4	327.9
#40	394.8
#100	265.5
#200	100.3
Pan(-200)	12.8