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A Tool to Improve and Preserve Flexible Pavement at Intersections

Carlos Jesus Solis
University of Texas at El Paso, cjsolis@miners.utep.edu

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CARLOS JESUS SOLIS

Department of Civil Engineering

APPROVED:

Soheil Nazarian, Ph.D.

Vivek Tandon, Ph.D.

Peter Golding, Ph.D.

Patricia D. Witherspoon, Ph.D.
Dean of the Graduate School

A TOOL TO IMPROVE AND PRESERVE FLEXIBLE PAVEMENT AT INTERSECTIONS

by

CARLOS JESUS SOLIS, B.S.C.E.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

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 primary goal of this project is 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.

Since the sources of excessive distresses at the intersections and their possible solutions are diverse, an easy-to-use excel program is proposed to incorporate the knowledge gained. The program will provide step-by-step guidance on the process of identifying the source of the problem, and selecting the best cost-effective alternative to mitigate the problem. The body of evidence from other countries with vast network of low-volume roads indicates that the most economical and effective solutions are those that strengthen the shallow subgrade or base instead of adding layers of hot mix or concrete.

1.1.1 Low-volume Roads

Most roads in rural areas are low volume roads. A road is considered low volume by AASHTO (2001) when subjected to an Average Daily Traffic (ADT) of less than 400 vehicles and are characterized by lower speed limits. While TxDOT (2006) classification for low volume road is where average daily traffic (ADT) is less than 1,000 vehicles per day (vpd) and cumulative ESALs are less than 500,000 for a design period of 20 years.

A well planned, located, designed, constructed, and maintained low-volume road system is essential for community development, flow of goods and services between communities, and resource management activities (Keller and Sherar, 2003). Such roads are necessary to serve the people in rural areas, allow the flow of products and services, facilitating commerce, and improving development.

1.1.2 Traffic

Traffic load, especially from truck traffic, is a major parameter in the development of rutting and fatigue cracking within the pavement. Overloaded trucks cause a disproportionate amount of damage to the pavement structure, accelerating such deterioration (SADC, 1999). At high stress locations, such as intersections, the braking and accelerating of vehicles increase the damage to the pavement structure, leading to more significant permanent deformation and fatigue cracking.

Several factors that resulted in increased rural truck traffic in Texas were identified and discussed by Prozzi et al. (2004). These factors include:

- Agricultural industrialization resulting in fewer but larger farms and the trend toward moving products between specialized operations predominantly by trucks;
- Increases in the physical sizes of agricultural equipment and the trend toward joint ownership or the lease of large and expensive pieces of farm equipment or outsourcing these services, resulting in increased movements on rural roads;
- Economic revival of the oil industry, resulting in relatively short but high-volume "heavy" movements;
- House Bill 2060 that allows the trucking industry to purchase permits at a nominal fee that allow 84,000-lb vehicles (gross vehicle weight) to traverse roads posted for 58,240 lb (gross vehicle weight);
- Location of large distribution centers of retail chains, such as Wal-Mart, HEB, and Target, in rural counties, where land is comparatively inexpensive and major highways provide access to major metropolitan markets;
- Location of landfill sites in western and northern Texas, which have raised concerns about pavement rutting caused by overloaded garbage trucks;
- Dramatic increases in truck traffic resulting from the North American Free Trade Agreement (NAFTA) that traverse a number of rural counties in Texas; and
- The abandonment of approximately 2,400 miles of rail track in Texas, following the Staggers Act, which has decreased the potential for large Class I railroads to service rural shippers, resulting in a large number of bulk commodities being moved on rural roads.

The recent popularity of harvesting wind energy by constructing wind farms, also contributes to this problem.

1.2 OBJECTIVES

The basic objective of this thesis 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. Develop (minimum) pavement design for rural and urban intersections, and
5. Develop draft specifications for flexible pavement construction for rural intersections.

1.3 SCOPE OF STUDY

The ultimate objective of this research is to establish a new guide that would hopefully provide the following information to pavement engineers:

1. Identify most prevailing distresses at an intersection, provide the source of the problem and which layer of the pavement structure is failing;
2. Propose most appropriate rehabilitation and/or maintenance procedures, to repair and prevent future failure of the pavement structure
3. Create an interactive design program to guide users through distress identification, remediation selection, and design procedures for low volume road intersections;
4. Provide feasible design alternatives and remediation strategies to minimize cost without compromise performance.

The specific scope of work for this thesis is to create a program that will serve as a preliminary guide as a step in the process of developing the final interactive design program.

1.4 ORGANIZATION OF THESIS

Chapter Two contains a substantial literature review with work done on this matter 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. Current flexible pavement design software is described and their advantages and limitations are identified. And finally different methods of cost analysis are explained, compared, and discussed.

Chapter Three describes the overall research approach. 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 a thorough pavement analysis of an intersection in the Texas district of Atlanta. The intersection of SH155 and SH49 was examined using both destructive and Non-Destructive Testing (NDT). A Visual Condition Survey was performed and Cores were extracted from strategic locations. Falling Weight Deflectometer and Ground Penetrating Radar was performed for both roads. Results obtained from Laboratory testing on the cores, FWD, and GPR are summarized, analyzed and discussed. Laboratory results from the cores, and the interpretation of deflection and radar data is summarized. Deep interpretation of the results allowed generating conclusions on the type and source of the problem.

Chapter Five includes a preliminary utility of the excel sheet developed to assist in the selection of remediation strategies. The site analyzed in Chapter 4 is evaluated in the preliminary guide for the selection of a more cost-effective remediation strategy. Life cycle cost analysis results are discussed for the repair alternatives.

Chapter Seven includes a summary of findings, conclusions, future work ahead and recommendations for future research.

CHAPTER 2: REVIEW OF LITERATURE

2.1 OVERVIEW OF ROAD INTERSECTION CONDITIONS

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) 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.

2.2 COMMON TYPES OF DISTRESS ON ASPHALT PAVEMENTS

2.2.1 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.

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.

2.2.1.1 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.

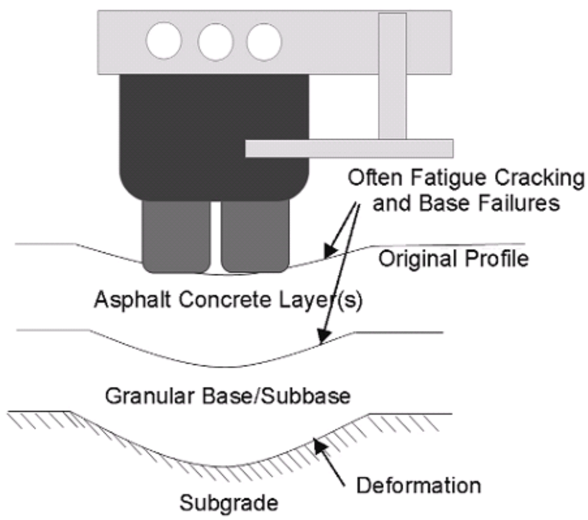
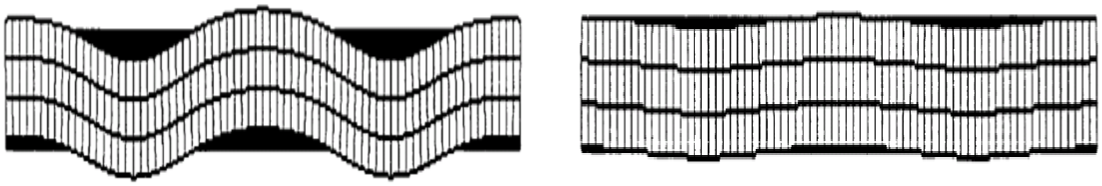


Figure 2.1: Structural Rutting on Asphalt Pavements (Federation of Canadian Municipalities and Canadian National Research Council, 2003).

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. Figure 2.2 illustrates and compares 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).



a) Base Failure b) Subgrade Failure

Figure 2.2: Surface Deformation Due to Base and Subgrade Failure. (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. Miss-estimation of these parameters leads to inadequate design and affect the pavement system which could induce structural rutting.

2.2.1.2 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 (1990) 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 2.3.

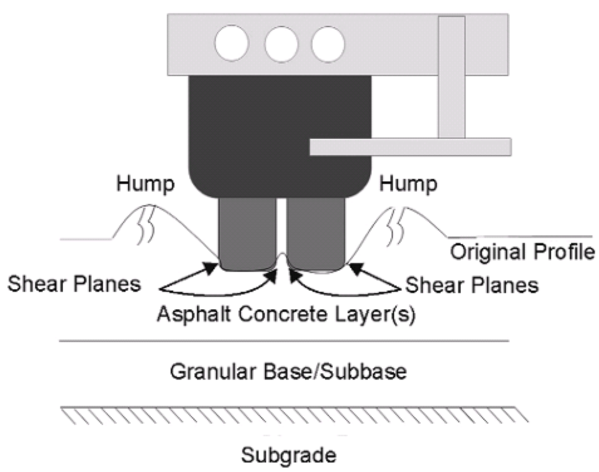


Figure 2.3: Instability or Plastic Flow on Asphalt Pavements (Federation of Canadian Municipalities and Canadian National Research Council 2003).

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 by 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 Department of Transportation Pavement Design Guide (CDOT, 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.

2.2.1.2 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 2.4. According to CDOT (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

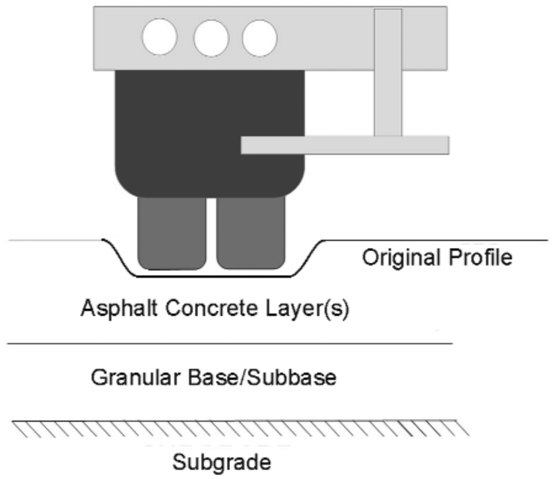


Figure 2.4: Wear Rutting on Asphalt Pavements (Federation of Canadian Municipalities and Canadian National Research Council 2003).

- 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.

2.2.2 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 2.5. Excess binder in the mix, mistakes in 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

Figure 2.5: Shoving on Asphalt Pavements.

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.

2.2.3 Fatigue Cracking

Fatigue in asphalt pavement manifests itself in the form of cracking from repeated traffic loading (Suo and Wong, 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 2.6.

Fatigue cracking is an important mechanism in the deterioration of asphalt pavements 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.

2.2.4 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,

Figure 2.6: Shoving on Asphalt Pavements.

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 distresses present at intersections which according to the Long-Term Pavement Performance Program (2005) are potential mixture related performance problems.

2.3 REMEDIATION STRATEGIES OF ASPHALT PAVEMENT AT INTERSECTIONS

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, white-topping, 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.

2.3.1 Current TxDOT Specifications for Flexible Pavement Rehabilitation

According to the TxDOT Pavement Design Guide (2006) 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 requires 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 can show the 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 are 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.

2.3.2 Asphalt Institute

The Asphalt Institute (AI) published a set of articles named "Intersection Strategy" (e.g., 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.

2.3.2.1 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 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.

2.3.2.2 Ensure Pavement is Structurally Adequate

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.

2.3.2.3 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 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. Table 2.1 indicates the Superpave binder selection adjustments for different ESAL and loading rates. 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 US, PG 76-XXs should perform well at intersections (Buncher, 2002).

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 (PGAC) Selection Adjustments (Bumping) 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

2.3.2.3 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 HMA at appropriate temperatures
- 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.

2.3.2.3 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.

Mill and Overlay with Asphalt Concrete

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.

Rut Filling Using Spray Patching, Thin Overlays, or Micro-Surfacing

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.

Grinding and Precision Milling

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.

White-topping (Conventional and Concrete Inlay)

White-topping is defined as the construction of a new Portland Cement Concrete (PCC) over an existing flexible pavement. White-topping 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 white-topping is generally suitable for the traffic loading associated with urban road intersections. PCC is designed as if it was on a treated base course.

Ultra-Thin White-topping

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 white-topping 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 White-topping (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 placed over the RCC may provide a smoother ride for the driving public.

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 4in. 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.

2.3.3 Canada

The Federation of Canadian Municipalities and Canadian National Research Council (2003) have developed a comprehensive guideline for rehabilitation of intersections. Figure 2.7 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.

2.3.4 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

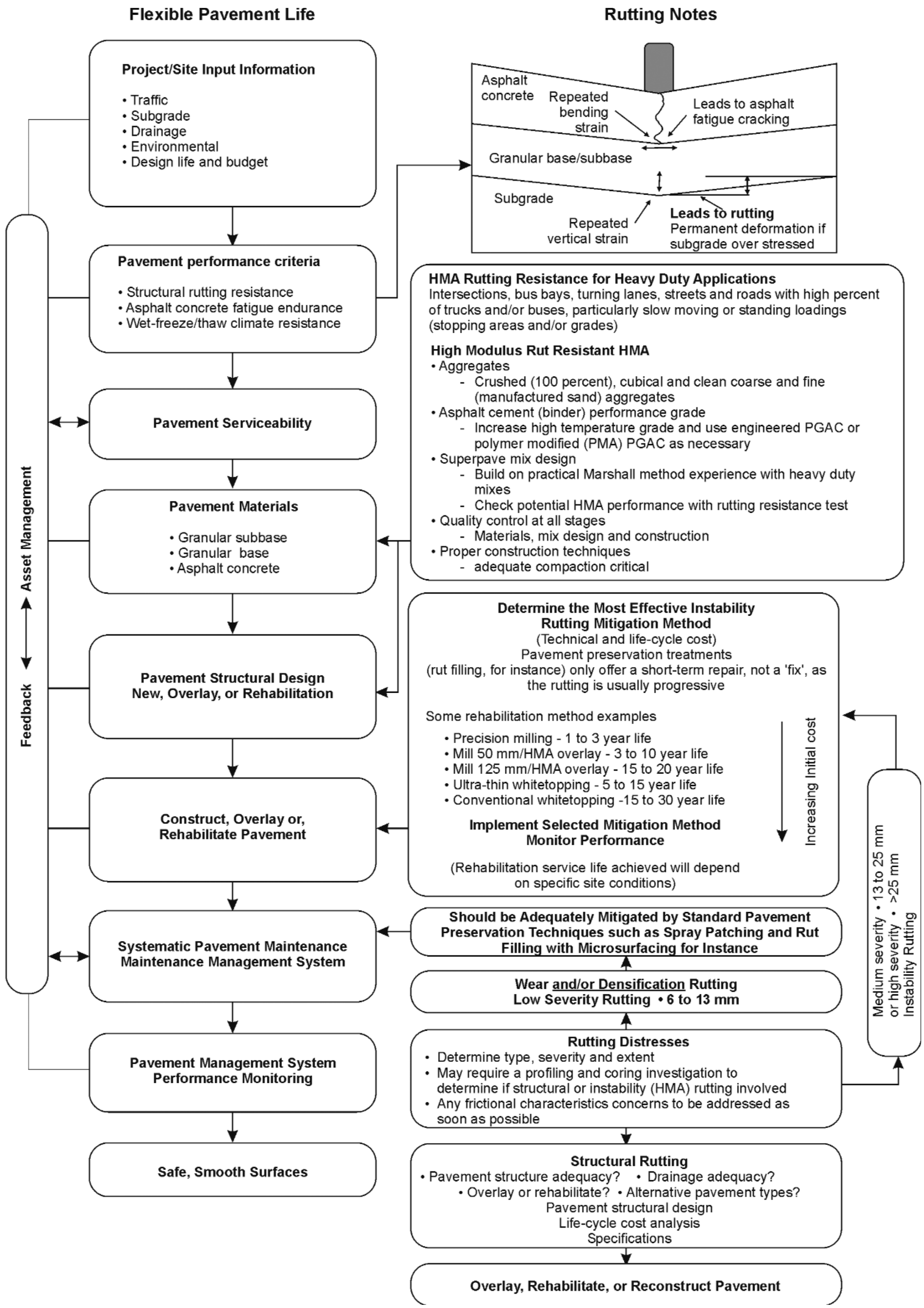


Figure 2.7: Flowchart of Activities for Mitigating Intersection Rutting.

subgrade layers leading to lack of support and thereby deformation of the complete pavement structure. The key items 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.

CDOT designs 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 adds up to one million ESALs or more.
- 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 ft in both directions. When one-way traffic, transition should be at least 300 ft on the deceleration side and 100 ft on the acceleration side of the intersection.
- A PG 76-28 binder is suggested by the CDOT for intersection pavements. "Bumping" binder grades would improve performance of asphalt. Superpave procedure to select binder grade for asphalt intersections is recommended.

2.3.5 Australia

The Australian Asphalt Pavement Association (AAPA, 1999) provides an advisory note entitled "Bituminous Surfacing for Intersections on Light and Medium Duty Flexible Pavements" as a guide to utilize spray seal (chip seal in the US) and other bituminous treatments over unbound and lightly bound granular pavements, especially in rural areas. A spray seal is

done by spraying a layer of binder on top of a damaged road surface and then covering it with aggregates. 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 spray seals can be improved by different methods, but supplementing the spray seal with a thin layer of HMA can improve smoothness and appearance, representing a longer term cheaper alternative. Performance of spray seals for high stress situations can be enhanced by:

- Polymer Modified Binders (PMB): also called High Stress Seals (HSS) to boost binder cohesion, toughness and improve temperature resistance.
- Multiple applications of binder and aggregate to produce a stronger spray seal. They recommend two applications of aggregates, the second one having predominantly aggregates half the size of the first one. This will allow the smaller aggregate to be accommodated within the voids left by the larger aggregates, providing a better clutch and therefore a stronger structure against vehicle shearing forces.
- Multiple application of aggregate ("racked in" or "dry lock" techniques) by light application of a small size aggregate (0.2in.) over a coarser aggregate sprayed seal in order to prevent the coarse aggregates from rolling away during seal compaction.

Guidelines for asphalt surfacing for intersections and roundabouts are as follows. For lightly trafficked pavements, the surface of the pavement has to be primed. For clean and in good condition primed surfaces tack coat may not be necessary, so it may be either reduced or discarded. Since a dense surface finish and durability are the main requirement, small aggregate sizes in a fine texture and workable mixes are usually used.

For medium trafficked pavements a common alternative is the construction of a sprayed seal pavement with asphalt surfacing in areas where vehicles turn, such as intersections, medians and roundabouts. The granular pavement should be surfaced with a prime seal or prime and sand

but first they should be allowed to dry to a moisture content no greater than 70% of optimum. If possible, before any asphalt surfacing is performed, the seal should be also given some time to allow compaction under traffic and evaporation of cutters. High level of cutters may lead to bleeding of the asphalt surfacing. 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 4 or 6 in. thick dense graded asphalt mixes are used for most medium to heavy traffic conditions.

2.3.6 New Zealand

Transit New Zealand (2004) has a supplementary document to the Austroads (The National Association of Road Transport and Traffic Authorities in Australia) called "Pavement Design – A Guide to the Structural Design of Road Pavements" which considers the high lateral stresses induced at intersection and thereby requires attention while designing and constructing all 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 strengths 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. In New Zealand, Stone Matrix Asphalt (SMA) has shown very good performance in terms of shear resistance and favorable surface properties.

2.3.7 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 in rural areas or 800 in urban areas. For ramps and other one-way facilities, one-half of this ADT criterion is recommended.
- 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 Superpave AC with an N_{design} greater than 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 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 cases that the HMA mixtures seem to be stable but the problem persists, then an exception to the high-

stress intersections criteria should be considered. Example conditions which may allow 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 single unit (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).

2.3.8 Hot Mix Asphalt Mixtures for Nevada's Intersections

The Nevada Department of Transportation (NDOT) uses a coarse dense graded HMA that 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. Hajj et al. (2007) developed specific requirements for hot mix asphalt mixtures for Nevada intersections. In that study, Hajj 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. He recommended the following criteria to assess the permanent deformation for mixes placed at the intersections and stopping areas:

- 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 in. at 140°F after 8,000 cycles.

2.3.9 National Center for Asphalt Technology (NCAT)

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

- 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.
- Coarser Gradation: Finer gradations or over-sanded mixes are more susceptible to permanent deformation.
- Angular and Rough Textured Aggregate: This is especially applicable to the fine aggregate fraction. Kalcheff and Tunicliff (1982) and Brown and Cross (1992) have demonstrated that mixtures utilizing angular manufactured sand are more resistant to permanent deformation than mixes produced with rounded or sub-rounded natural sand.
- 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.
- 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.
- Higher Fines Content: Increase in the minus 200 sieve fraction of the mix will tend to stiffen (increase the viscosity) of the binder.
- 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.
- 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.

- Improved Bond between Pavement Layers: A lack of good bond between the pavement layers (especially in top 6in. of the pavement) can cause slippage due to horizontal thrust.

The following mixtures were recommended by Kandhal (1998) for use at intersections in hot climates:

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

2.4 REMEDIATION STRATEGIES CONSIDERING SUBSURFACE LAYERS OF PAVEMENTS

2.4.1 Base Layer

Structural inadequacy can be cause by subsurface layers as much as the HMA layer. 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 will not solve the problem. The remediation strategy needs to address the base layer. Most of the time the under-designed base layer can be remedied by stabilization or 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. Smaller amounts of additives are required to modify soil properties such as 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
- Increasing durability and strength
- Reducing dust during construction
- Waterproofing the soil
- 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 materials 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 2.8 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.

A simple mechanical stabilization alternative 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 mechanically stable layer by lowering the PI and optimum moisture content (OMC), and by improving the strength and the workability of the material.

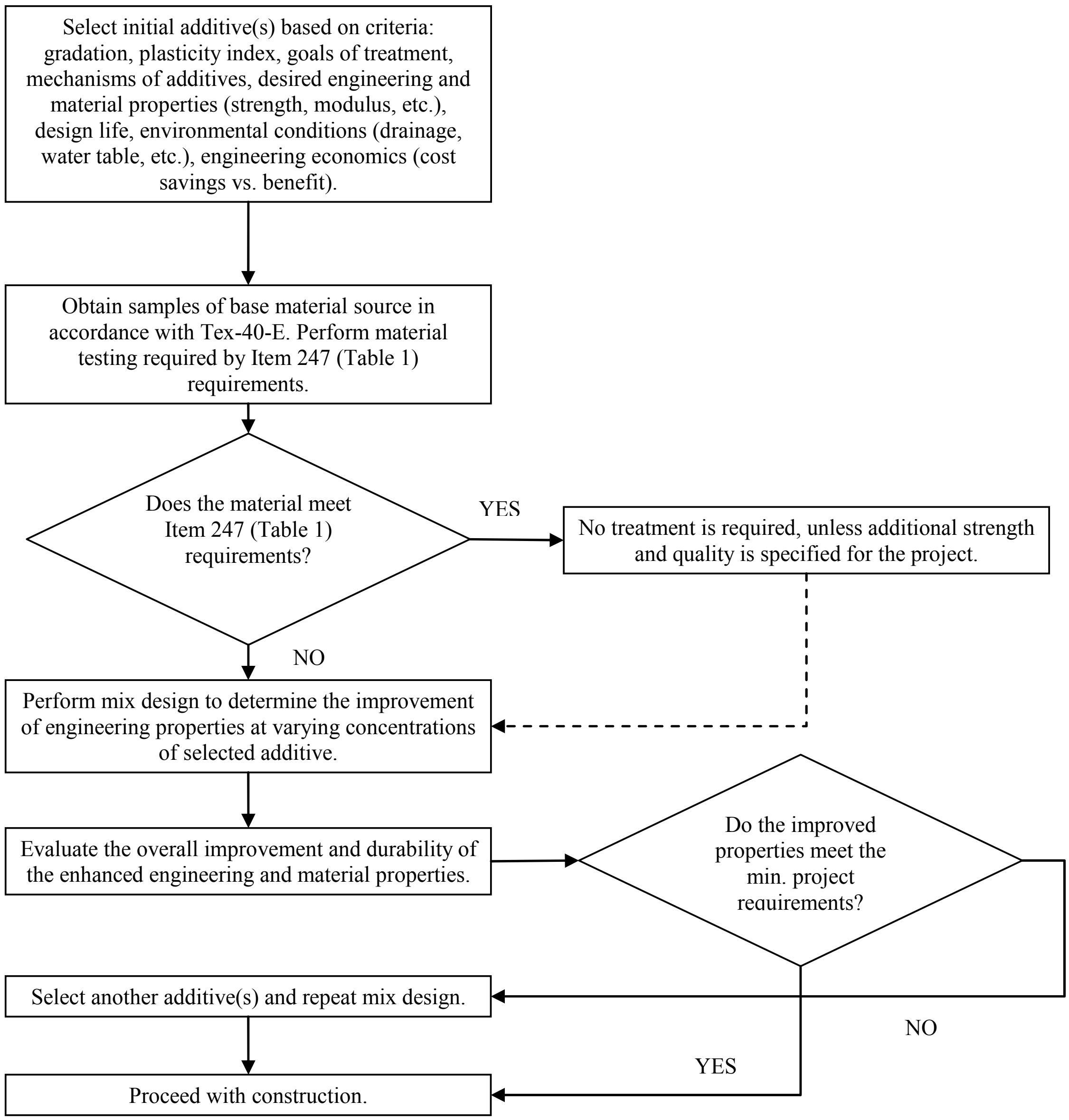


Figure 2.8: TxDOT Flowchart for Base Treatment (TxDOT, 2005a).

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 waterproofers, lime modification
Clays of high plasticity	Lime stabilization

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

2.4.1.1 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.

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, 1999). 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. 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, 1999). 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.

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 lead 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.

2.4.2 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. Common remediation methods can be categorized into two groups: (1) to improve strength and (2) to minimize moisture variation. To improve soft subgrade bearing capacity and strength, thicker layers of high-quality granular material may be used on top of the problematic subgrade. In other instances, stabilization and geosynthetic reinforcement can be used. The common strategies used to minimize moisture variations and fluctuations 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 minimize 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 vegetations.

2.4.2.1 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 et al., 2000). Little (1999) indicated that lime stabilization often induces a ten fold 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. 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 than Portland cement stabilized layers. As with strength properties, resilient properties of lime-soil mixtures are 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. If the sulfate levels are above 3000 ppm, further recommendations and guidelines can be found in TxDOT (2005b). Puppala et al. (2003, 2004) 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). 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, 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).

2.4.2.2 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 in the subgrade.

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. 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. Ravina (1984) and Snethen (2001) 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. The type and location of trees should be considered in landscaping decisions, particularly involving soil having LL > 40 and PI > 25. Based on the relative average rank analysis, the most influential trees are Poplar, Elm, oak, and Ash. These types of trees should be planted at least 1.5 to 3 ft beyond the anticipated mature drip line or the anticipated mature height of the tree from pavements (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 ft and the lime fillings should be 4 to 8 in. 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.

2.4.2.2 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 geocomposties

(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 Kwon, 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 have been found to give overall higher geosynthetic stiffness and hence work better than geotextiles (Giroud and Han, 2004a, b).

The four major functions of geosynthetics used in pavements are: reinforcement, separation, filtration and drainage (Helstrom et al. 2007). 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).

The inclusion of geosynthetics in flexible pavement design is difficult since a number of uncertainties arise when geosynthetics is applied under distress. 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. Low-volume road pavements typically consist of a thin 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 developed at the bottom of the granular layer will cause 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 2.9). Use of geosynthetic reinforcement in such situation is gaining favor (Hufenus et al., 2006; Hopkins et al., 2005)

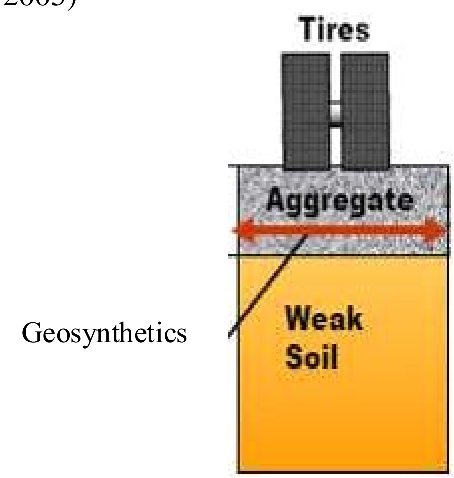


Figure 2.9: Improving Pavement by Using Geosynthetics (from Hopkins et al., 2005).

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).

Inclusion of geosynthetics in both wet and dry conditions increases the tensile strength of the subsoil (Gurung, 2003; Abd El Halim, 1983). 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) recommend using an average design improvement factor of 1.8. Kwon, et al. (2008) demonstrated the benefit of using geogrids in pavement base course reinforcement based on a full-scale test study. 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) indicated 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.

2.6 CURRENT FLEXIBLE PAVEMENT DESIGN SOFTWARE AND LIMITATIONS

2.6.1 TxDOT Flexible Pavement Design System (FPS-19)

The Flexible Pavement Design System (FPS-19) is the preferred method for designing flexible pavements in Texas. It provides a methodology for selecting a complete pavement design strategy which includes initial construction and rehabilitation or reconstruction. The

material properties required by the FPS-19 to perform the pavement design are the moduli of pavement layers. These values are backcalculated from the Falling Weight Deflectometer (FWD) data using the MODULUS software system. Along with the modulus the expected number of 20-yr 18-kip Equivalent Single Axle Loads (ESALs) is required by the FPS-19 to determine the design thicknesses for the specified pavement materials and layers. Beside traffic and material, environmental parameters are also considered by FPS-19. The output of the software consists of one or more recommended strategies, depending upon the material layer thicknesses the designer is willing to consider. For low volume roads, the adequacy of the design with the FPS 19 in protecting the subgrade is verified using the Modified Texas Triaxial design method.

2.6.2 AASHTO's DARWin

DARWin is the software created based on the 1993 AASHTO Guide for Design of Pavement Structures. It is a complete pavement design and analysis software for both initial design and rehabilitation. The procedure requires the user to calculate a Structural Number (SN) that will satisfy the performance requirements for an anticipated traffic over an expected life. The equation for SN is shown below and is equivalent to the sum of a layer coefficient a, layer thickness D, and drainage coefficient m for each layer.

$$Structural\ Number\ (SN) = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3, etc. \quad (2.1)$$

One factor that makes this design software somewhat problematic is that layer coefficients are not directly correlated to any universal system of measurement. AASHTO does provide some guidelines for correlation to laboratory-derived resilient modulus and one design option using the DARWin software is to input layer resilient moduli instead of layer coefficients. Although, one of the main advantages of this software over the rest is the Life-Cycle Cost Analysis it performs for each design alternative.

It is important to point out that none of the actual flexible pavement design software described address intersections separately. The only considerations taken are based on previous experiences from the designer and the adjustment to the accumulation of ESALs. None of the described programs take into account the effect of stop/slow-moving vehicles in the permanent deformation of pavement at intersections.

2.7 COST AND BENEFIT ANALYSIS

2.7.1 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).

2.7.2 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:

$$Present\ Value = Future\ Value \times \left(\frac{1}{(1+r)^{n_k}} \right) \tag{2.2}$$

$$Total\ Present\ Value = Initial\ Cost + \sum Future\ Value \times \left(\frac{1}{(1+r)^{n_k}} \right) \tag{2.3}$$

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.

2.8 SUMMARY

The literature review presented above describes the characteristics and mechanisms of the most common types of distresses on asphalt pavements and covered promising remediation strategies for such problems at different levels of the structure. Such remediation strategies were gathered from research and specifications by several organizations and state agencies throughout the United States and worldwide. Some of the remediation strategies discussed apply directly to flexible pavements at intersections. A collection of recommended strategies for each distress is summarized in Figure 2.11.

The characteristics and methodology of TxDOT's preferred flexible pavement design software FPS-19, and AASHTO's DARWin were described and their limitations were pointed out. Different cost analysis methods were compared and discussed, and the Life-Cycle cost analysis is described following the FHWA's methodology.

The results from the maintenance and rehabilitation methods for flexible pavements search are listed in Figure 2.10. The information is resourced from the 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.

Layers	**Distresses**	**Maintenance & Rehabilitation Methods**
Asphalt	**Surface Rutting** **Instability Rutting** **Shoving** **Fatigue Cracking**	**Microsurfacing** **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** **HMA & RAS Overlay**
Base	**Structural Rutting** **Shrinkage Cracking**	**Full Depth Reclamation** **Roller Compacted Concrete (Base)** **Stabilization** **Moisture Control**
Subgrade	**Moisture Intrusion** **Structural Rutting** **Shrinkage Cracking**	**Stabilization** **Moisture Control**

Figure 2.10: Probable Appropriate Remediation for Different Layers

A matrix that links probable distresses and the appropriate remediation resourced from the literature review is presented in Figure 2.11. The matrix aims 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. It divides the different distresses by the respective layer that is failing and subcategorizes some of them by severity. The different methods to repair flexible pavement are listed and separated into rehabilitations and maintenances. The figure

provides cases where a remediation is appropriate, likely or might be appropriate, not appropriate and finally not a candidate to solve the identified predominant distress. A legend to identify the suggestions is provided at the left bottom of the table.

Multiple maintenance and rehabilitation alternatives were evaluated in order to compile the matrix taking in consideration current TxDOT methods and some additional low cost alternatives. A thorough analysis of the suitability of each alternative to repair each of the predominant distresses at intersections was necessary to fill every space in the matrix. Hicks et al (2000) developed a framework for the selection of the most appropriate preventive maintenance and rehabilitation treatments after reviewing existing practices. Some of the recommendations made by Hicks were considered for the matrix along with recommendations made by the Ontario Hot Mix Producers Association (OHMPA) on their ABCs of Pavement Preservation (2004). One of the major factors missed by other agencies was 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 matrix on Figure 2.11 contains the different types of rutting (surface, instability, and structural) by separate taking in consideration that they all come from different sources and thereby should be approached differently.

All the recommendations are under the assumption of good design and construction practices. The proper identification of distresses is essential to the proper selection of alternatives. An extensive pavement analysis to recognize the type and cause of existing distresses is encouraged before recurring to the matrix of solutions.

The following sections describe the development of an excel program for strategies selection to improve and preserve flexible pavement at intersections, and the knowledge acquired is applied into a case study.

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	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	×	×	×
		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
* No TxDOT specifications

Figure 2.11: Remediation Strategies for Common Distress Indicators.

CHAPTER 3: RESEARCH APPROACH

3.1 TEXAS DISTRICTS SURVEYS

A questionnaire was developed and distributed to all Texas 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 purposes:

- 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.

The questionnaire is provided in Appendix A. The results to each question are documented sequentially.

Question 1: Do your pavements experience distress at the intersections of low volume roads?

There were 17 responses to the question as summarized in Figure 3.1. Sixteen districts stated that they experience distress at intersections of low volume roads.

Question 2: If yes, what percentage of the intersections experiences any type of distress?

The percentage of the intersections in each district that exhibit distress is listed in Figure 3.2. A limit of 25% distressed intersections was arbitrarily selected to distinguish those districts that have more problems with their intersections. Based on that limit, San Antonio, Lubbock, Houston and Fort Worth can benefit from the outcome of this research. Some of the remaining districts were contacted to learn what factors contributed to their lack of distress at intersections.

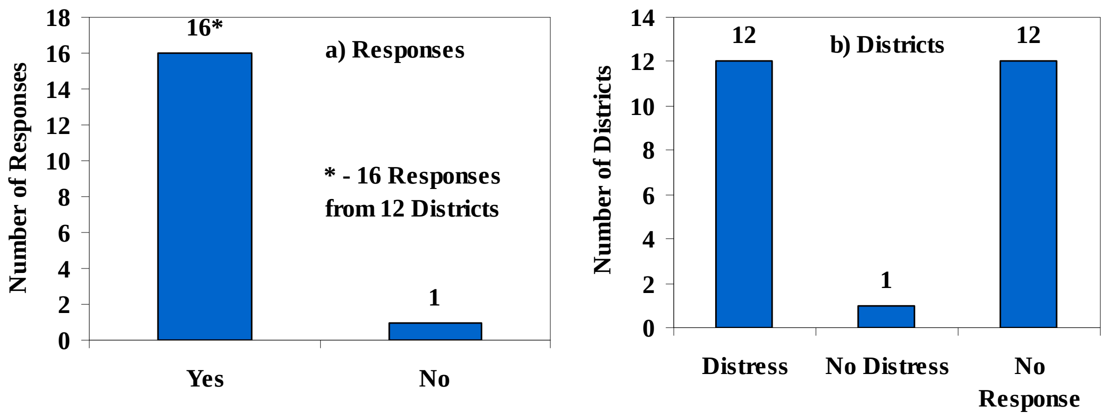


Figure 3.1: Results of Survey Responses to Districts Experiencing Distress at the Intersections of Low Volume Roads.

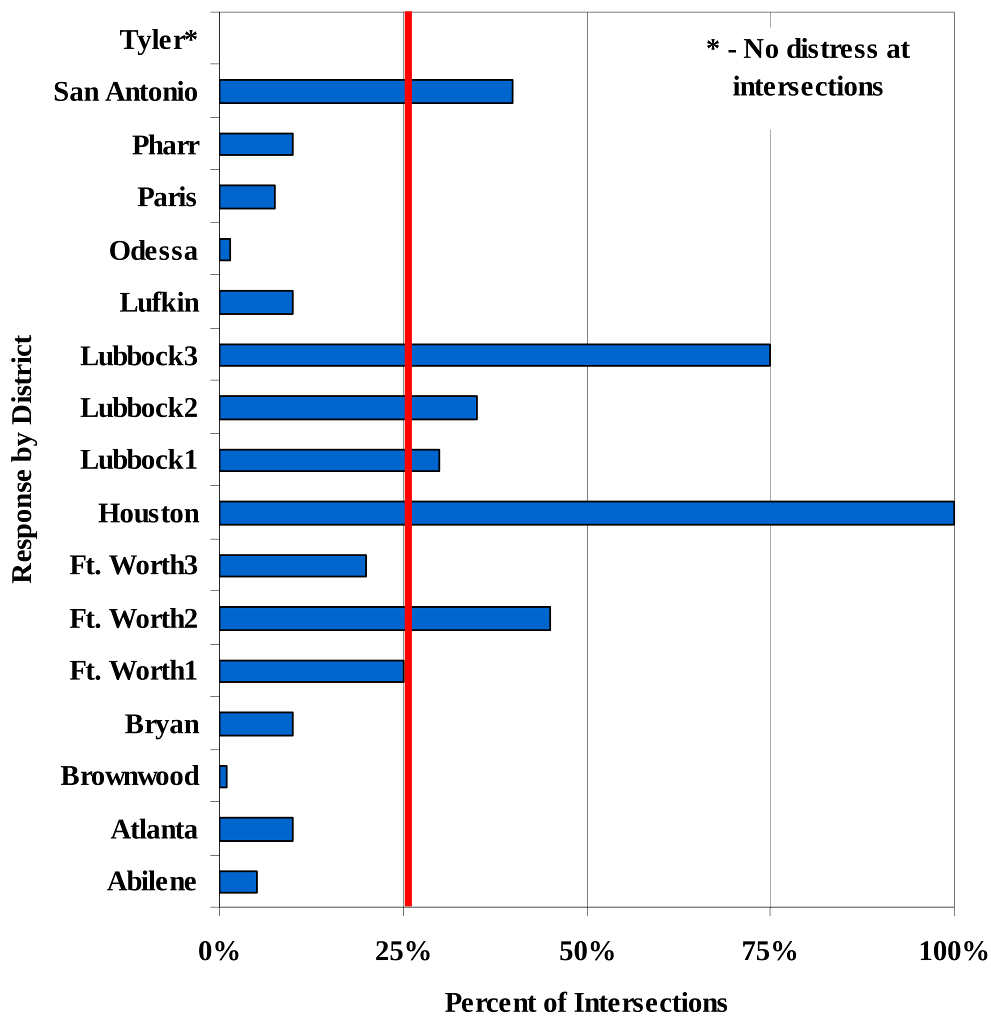


Figure 3.2: Percent of Intersections Experiencing Distress in the Districts.

Question 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 (___%)

Figure 3.3 summarizes the level of severity of distressed intersections for each district. As with Figure 3.2, a 25% limit of distressed intersections is highlighted as an arbitrary marker to distinguish the level of severity perceived by the districts. For most districts at least 50% of the distressed intersections are considered as low severity. Also, most districts perceive that about 25% of the distressed intersection fall within medium severity.

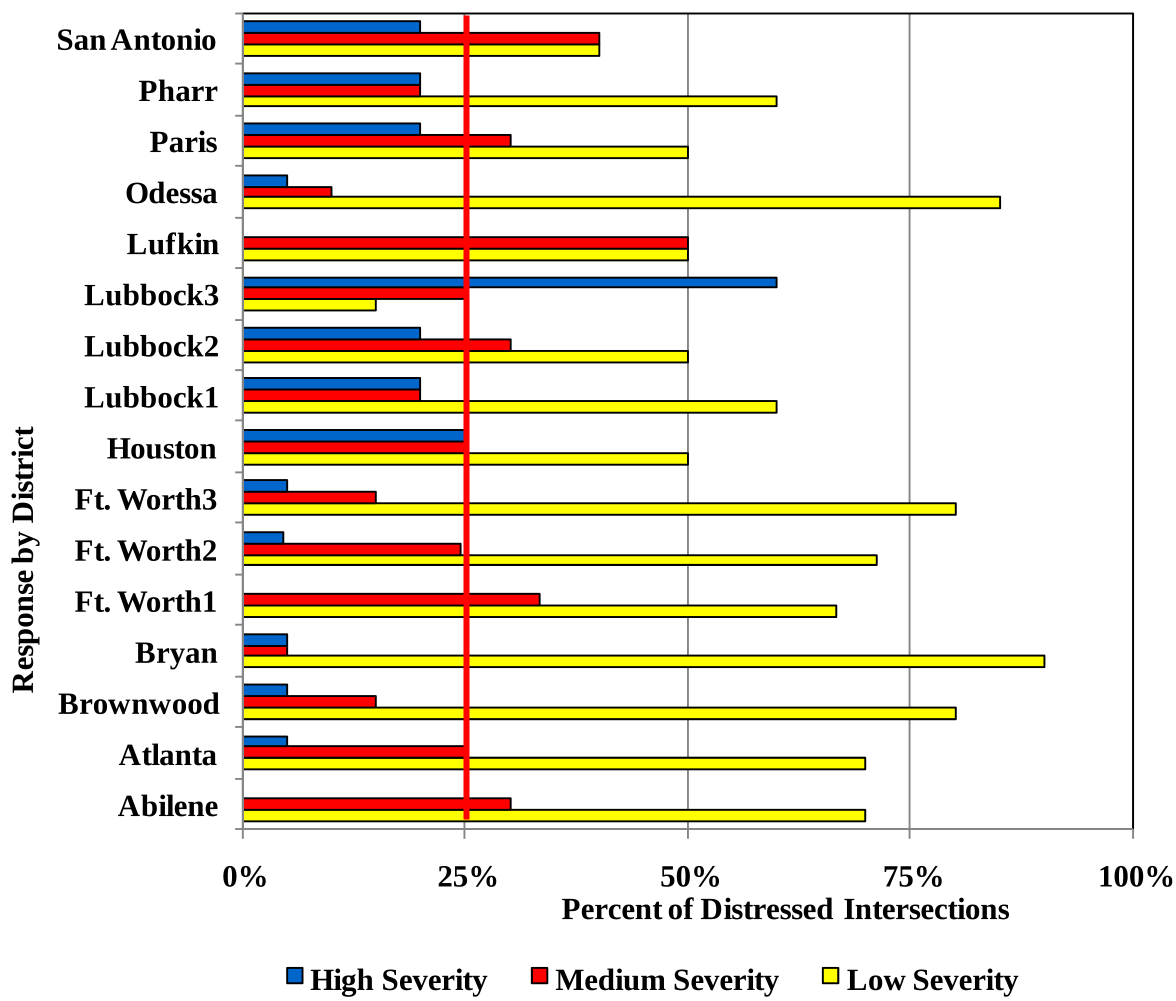


Figure 3.3: Distribution of Distress Severity at Distressed Intersections.

Question 4: What distress types are common at your intersections on low volume roads?

As presented in Figure 3.4, all four types of distresses listed in the survey are equally common at the distressed intersections. Other distresses documented were loss of aggregate, potholes, rolling of seal coat, rub board or wash board effect, and edge break off.

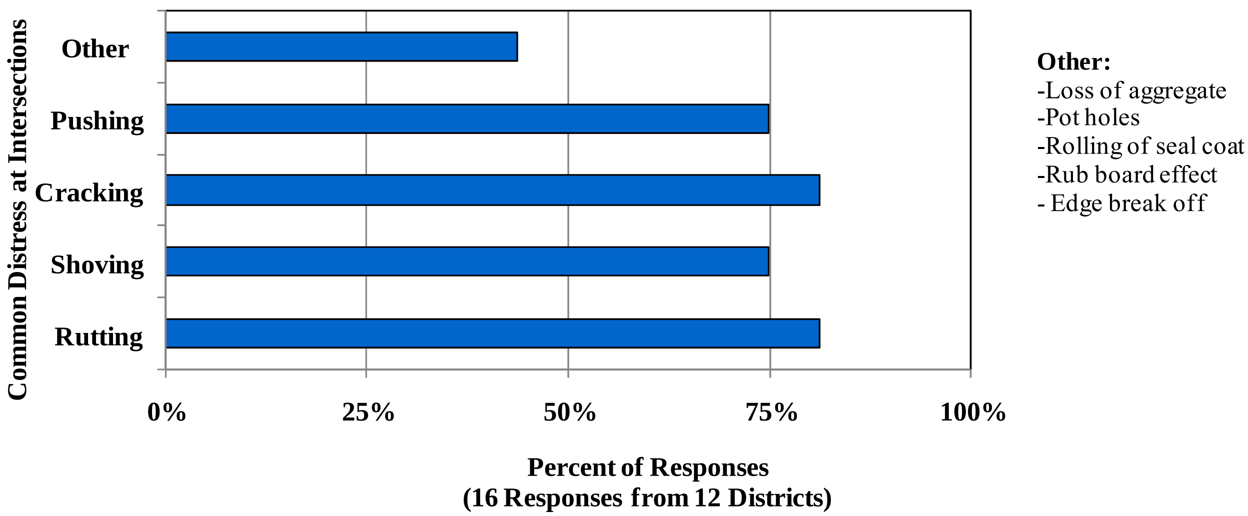


Figure 3.4: Type of Distress at Intersections.

Question 5-9 referred to the all five distresses listed in Question 4.

A sample of the question related to rutting is provided as an example in Figure 3.5 below.

(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)____________________

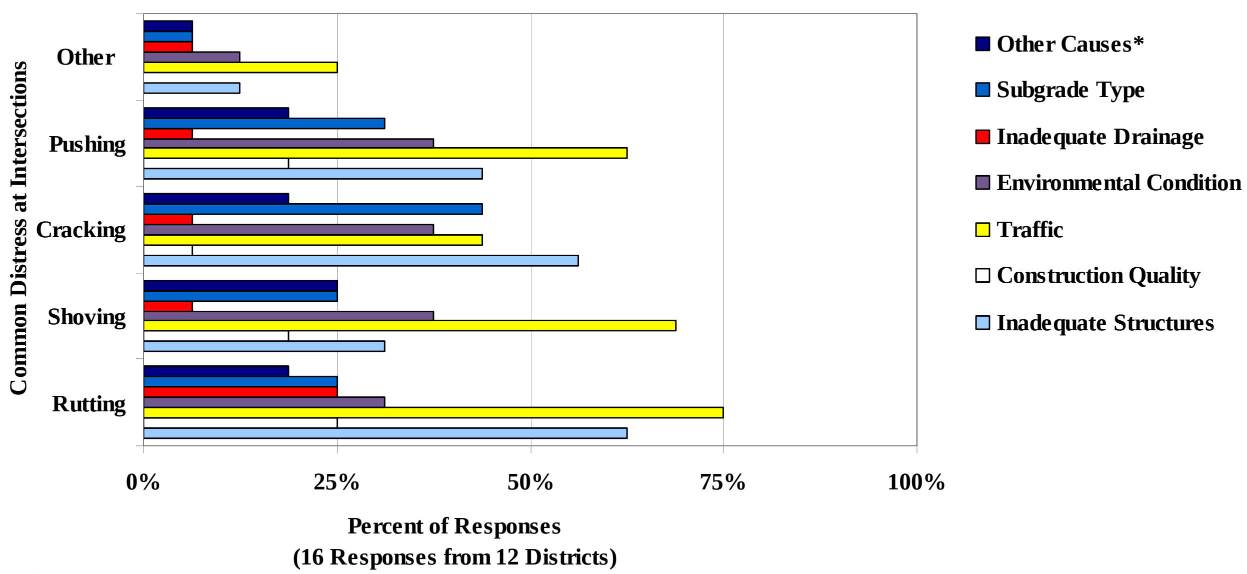
? Inadequate drainage____________________

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

? Other____________________

Figure 3.5: Question 5 from the Survey.

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



*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.

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

The responses to this question are summarized in two parts. The first part is a summary of the typical solutions. Appendix B provides tables that summarize the strategies selected by each district. 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. In addition, a

number of districts offered other means of remediation than those listed in the survey. For each distress, these strategies are also listed in Figure 3.7.

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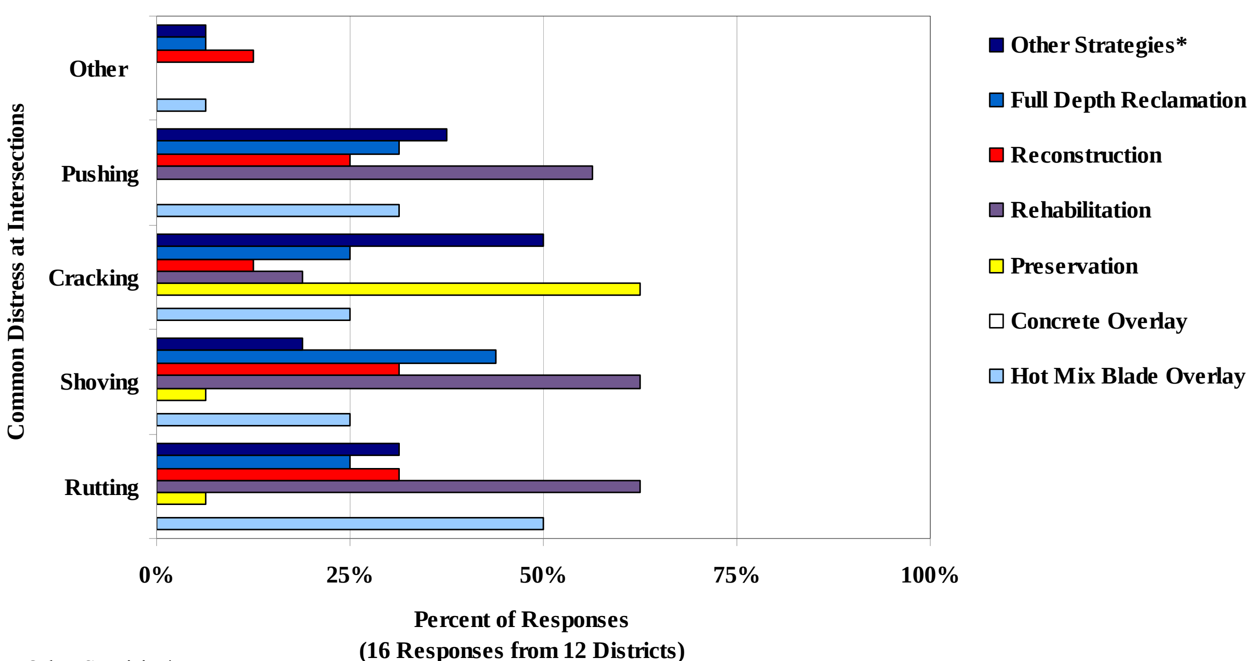


Other Stratigies*

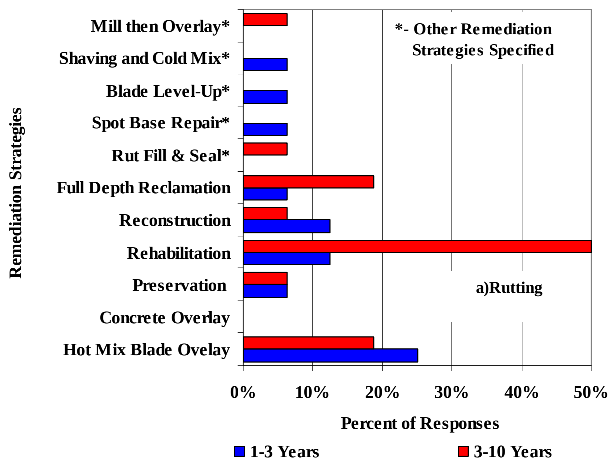
- Rutting : Rut fill & seal, spot base repair, blade level-up with maintainer, shaving cold mix overlay
- Shoving : Spot base repair, mill & blade level-up with maintainer, shaving and cold mix overlay
- Cracking : Crack seal, spot base repair, spot seal, crack pouring, fog seal, overlay, seal coat, scrub seal
- Pushing : Spot base repair, mill & blade level-up with maintainer, widing, shaving and cold mix overlay, good edge 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.

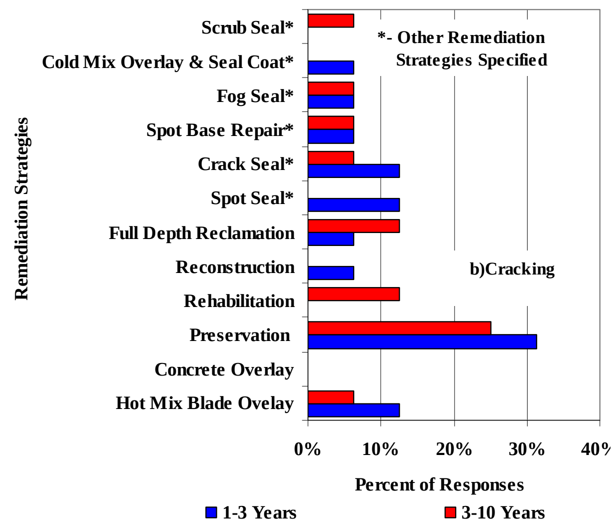
Question 10 also inquires about the typical performance life of each remedy. The results are presented in Figure 3.8. For all strategies listed the performance period is either 1-3 years or 3-10 yeas. For several of these strategies, the responses were mixed showing that some strategies work better in some districts than others.

The results from the questionnaire present a good first step in understanding and documenting the sources and problems at intersections. The results provide insight on several areas where more investigation is, which were targeted in a second questionnaire and interviews

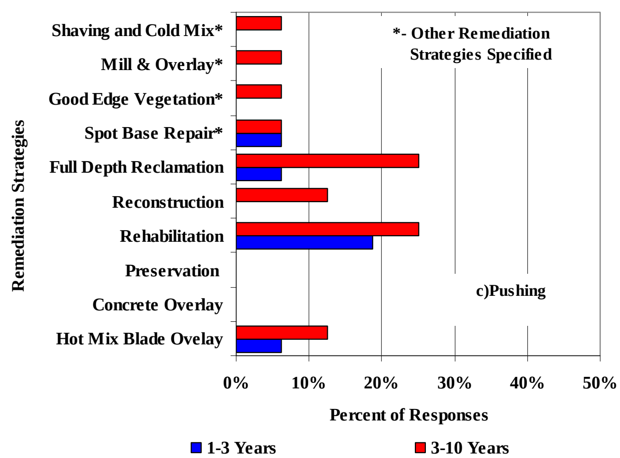
with district personnel. The summary of results from both the questionnaire and the interviews will be discussed further in this document.



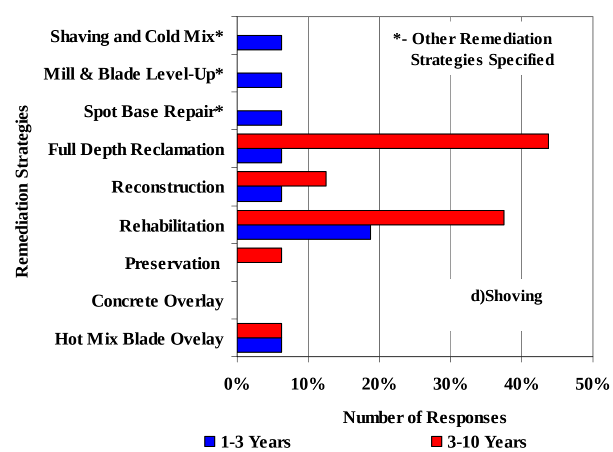
a) Rutting



b) Cracking



c) Pushing



d) Shoving

Figure 3.8: Typical Performance Period for Selected Remediation Strategies.

3.2 METHODOLOGY

Since the sources of distress at the intersections and the possible solutions are diverse, an easy-to-use Microsoft Excel spreadsheet was created to incorporate the knowledge gained as a preliminary guide for the selection of remediation strategies. The excel sheet contains a systematic approach in incorporating the matrix of solutions presented in Chapter 2. This excel

sheet guides the user through the process of identifying the proper remediation methods for flexible pavements at intersections and performing the life cycle cost analysis (LCCA) to obtain the most economical alternative. The methodology used to develop this tool and a case study are presented in this chapter. The methodology is schematically demonstrated in Figure 3.9. The software may be used, in a rational manner, for the following purposes:

- Finding the appropriate repair alternatives for a given flexible pavement structure, the dominant distress and traffic loading scenario.
- LCCA variables determination such as Initial Cost, Present Value, Total Present Value and Salvage Value.
- LCCA graphs for comparison of the recommended repair alternatives.
- Yearly ESAL determination based on the average AADT (Average Annual Daily Traffic) throughout the analysis period, the correlation for the number of 18 kip (80 kN0 single-axle load applications per truck, and the percentage of traffic traveling per lane on each direction.

A user interface manual for the spreadsheet is provided in Appendix C

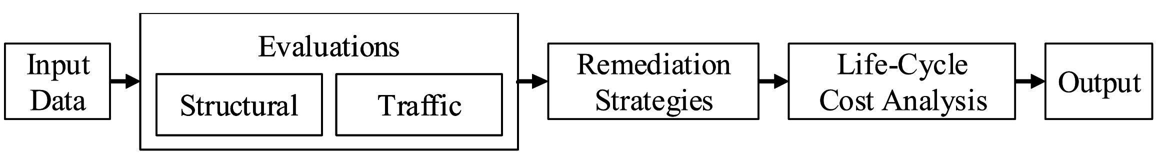


Figure 3.9: Methodology Diagram.

3.2.1 Input Data

The purpose of this section is to collect most of the information from users at the beginning of the program. This information is used throughout the analysis process.

Beside the general project information, the input data required for the analysis are:

- size of the project,
- intersection traffic count and factor,
- problematic layer, predominant distress and severity, and

- preferred future maintenance method when rehabilitation is recommended
- analysis period and discount rate

Other information related to parameters associated with different remediations such as unit costs and expected life has been included in Excel as default values. The default values are used with the flexibility of modifying this information is given to the users to fit their own conditions.

3.2.2 Evaluation

3.2.2.1 Structural Evaluation

The main purpose of this section is to evaluate the existing structural conditions of the intersection based on the information collected. In the excel sheet, the structural evaluation is based on visual inspection, making the visual identification of predominant distresses essential for the analysis. The most common flexible pavement distresses at intersections are presented in Chapter 2. Additional analysis is necessary to ensure the structural adequacy of the pavement structure and corroborate the conclusions made by visual inspection. Field tests such as Dynamic Cone Penetrometer (DCP) and Falling Weight Deflectometer (FWD) are good options to determine the existing modulus of the pavement layers for rehabilitation purposes. This information is not currently included in the preliminary guideline. However, an option will be provided in the final product to include input from field data such as FWD and DCP.

The sources of most typical distresses at intersections can be pointed to a specific pavement layer, thereby it is possible to identify the failing layer by recognizing the type of distress present. For example shoving, fatigue cracking, surface rutting and instability rutting are strictly related to failure due to the asphalt layer mixture. The source of structural rutting can be identified by paying attention in the details of the deformation. A small hump in the middle of the two wheel paths and narrower wheel paths indicate base deformation, while wider wheel paths with no hump between the wheel paths indicate deformation of the subgrade layer (Fang,

2001). Based on the importance of the project, these behaviors could be corroborated with further lab or field testing. The list of distresses currently incorporated into the guideline is:

- Instability Rutting
- Surface Rutting
- Shoving
- Fatigue Cracking
- Structural Rutting
- Moisture Intrusion

Identifying the magnitude or severity of the distress is also important. Severities of distresses are usually categorized as high, moderate, and low. The distresses categorized by severity are rutting (structural, instability, and surface) and fatigue (alligator) cracking. The remaining distresses are not categorized and are only evaluated based on their presence. Based on the predominant distress and the level of severity (if required), a number of remediation strategies are proposed. However, the traffic data and other information are also used to narrow the choices of remediation.

3.2.2.2 Traffic Evaluation

The traffic classification utilized is based on TxDOT criteria for low volume roads of less than 500,000 cumulative ESALs for a design period of 20 years. A value of 25,000 ESALs per year is used by the spreadsheet to classify low volume roads. Lower cost remediation alternatives are considered in the evaluation if the traffic volume is less than this value. Otherwise, the intersection is considered as a high-volume intersection, and the recommended alternatives will be those typical for high volume roads, such as Portland Cement Concrete (PCC) Overlay, Full Depth Reclamation, and Roller Compacted Concrete.

The following traffic information should be requested from the Transportation Planning and Programming Division:

- Truck Factor,

- Truck Percentage
- Lane Distribution Factor
- Average Annual Daily Traffic (AADT) for the year of construction, and
- Predicted Average Annual Daily Traffic (AADT) for the end of the analysis period.

One of the considerations that should be taken at this point is the summation of the AADTs from both roads intersecting to be able to quantify the actual number of vehicles passing through the intersection itself. The combination of trucks as percentage of AADT is necessary to calculate the number of heavy vehicles that will be using the road and it can be find in Table 3.1 by identifying the predominant truck classes and the type of the roads. The Truck Factor is the correlation for the number of 18-kip single-axle load application per truck and it can be found in Table 3.2. Finally the Lane Distribution Factor represents the percentage of truck traffic that is traveling in the design lane and can be obtained from Table 3.3. These values introduced in Equation 3.1 to calculate the Daily ESALs over the intersection necessary for the classification.

$$Daily\ ESAL = \left(\frac{AADT_i + AADT_f}{2}\right)(T)(T_f)(L)(0.5)(365) \tag{3.1}$$

where:

$AADT_i$ = Average Annual Daily Traffic during construction year

$AADT_f$ = Average Annual Daily Traffic projected at the end of analysis period

T = Truck Percentage

T_f = Truck Factor

L = Lane Distribution Factor

3.2.3 Remediation Strategies

Different distresses correspond to different solutions. A matrix that relates the most common distresses at intersections with the common remediation methods is presented in Figure 2.11. Remediation strategies are categorized into two types; rehabilitation and maintenance, while the distresses are categorized by layer, and then subcategorized by severities. The data in

the matrix is synthesized based on the literature and several expert opinions around Texas. This data will be incorporated into the remediation tool in the second phase of research. It could also be modified by including other distresses and or remediation strategies.

As soon as the problem is identified, the excel sheet looks up the feasible alternatives to repair the problem from the matrix and lists them. The alternatives are differentiated in the list by color, highlighting the "appropriate" in green and the "less appropriate" in yellow. A description of each remediation method consider by the matrix as an alternative for the typical distresses at intersections is contained in Appendix D.

Table 3.1: Distribution of Trucks on Different Classes of Highways in the United States after AI (1991)

Truck Class	Percent Trucks											
	Rural Systems						Urban Systems					
	Interstate	Other Principal	Collectors		Minor	Range	Interstate	Other Freeways	Other Principal	Minor Arterial	Collectors	Range
			Minor Arterial	Major								
Single-unit Trucks												
2-axle, 4 tire	43	60	71	73	80	43-80	52	66	67	84	86	52-86
2-axle, 6 tire	8	10	11	10	10	8-11	12	12	15	9	11	9-15
3-axle or more	2	3	4	4	2	2-4	2	4	3	2	<1	<1-4
All single units	53	73	86	87	92	53-92	66	82	85	95	97	66-97
Multiple-unit Trucks												
4-axle or less	5	3	3	2	2	2-5	5	5	3	2	1	1-5
5-axle*	41	23	11	10	6	6-41	28	13	12	3	2	2-28
6-axle or more*	1	1	<1	1	<1	<1-1	1	<1	<1	<1	<1	<1-1
All multiple units	47	27	14	13	8	8-47	34	18	15	5	3	3-34
All Trucks	100	100	100	100	100		100	100	100	100	100	

* Including full-trailer combinations in some states
+ Compiled from data supplied by the Highway Statistics Division, U.S. Federal Highway Administration

Table 3.2: Distribution of Truck Factors for Different Classes of Highways and Vehicles in the United States after AI (1991)

Truck Class	**Truck Factors**											
	Rural Systems						**Urban Systems**					
	Interstate	**Other Principal**	**Collectors**		**Minor**	**Range**	**Interstate**	**Other Freeways**	**Other Principal**	**Minor Arterial**	**Collectors**	**Range**
			Minor Arterial	**Major**								
Single-unit Trucks												
2-axle, 4 tire	0.003	0.003	0.003	0.017	0.003	.003-.017	0.002	0.015	0.002	0.006	-	0.006-0.015
2-axle, 6 tire	0.21	0.25	0.28	0.41	0.19	0.19-0.41	0.17	0.13	0.24	0.23	0.13	0.13-0.24
3-axle or more	0.61	0.86	1.06	1.26	0.45	0.45-1.26	0.61	0.74	1.02	0.76	0.72	0.61-1.02
All single units	0.06	0.08	0.08	0.12	0.03	0.03-0.12	0.05	0.06	0.09	0.04	0.16	0.04-0.16
Tractor semitrailers		0.92	0.62	0.37	0.91	0.37-0.91	0.98	0.48	0.71	0.46	0.4	0.40-0.98
4-axle or less	0.62	1.25	1.05	1.67	1.11	1.05-1.67	1.07	1.17	0.97	0.77	0.63	0.63-1.17
5-axle*	1.09	1.54	1.04	2.21	1.35	1.04-2.21	1.05	1.19	0.9	0.64	-	0.64-1.19
6-axle or more*	1.23	1.21	0.97	1.52	1.08	0.97-1.52	1.05	0.96	0.91	0.67	0.53	0.53-1.05
All multiple units	1.04	0.38	0.21	0.3	0.12	0.12-0.52	0.39	0.23	0.21	0.07	0.24	0.07-0.39
All Trucks	0.52											

* Including full-trailer combinations in some states
+ Compiled from data supplied by the Highway Statistics Division, U.S. Federal Highway Administration

Table 3.3: Lane Distribution Factor after AASHTO (1986)

No. of Lanes in Each Direction	Percentage of 18-kip ESAL in Design Lane
1	100
2	80-100
3	60-80
4	50-75

3.2.4 Life-Cycle Cost Analysis

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 pavement design on the future cost of 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. Since this research is focused on rural road intersections with low daily traffic, the user costs (user delay costs, vehicle operating costs, and crash costs) and the construction activity timing were omitted from the analysis.

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. Unit costs and expected lives of each alternative were collected from the literature and provided in the program as default values for the analysis. These costs are expected to vary with location and the expected lives would also vary depending on the environmental conditions. Thus, these values can be readily adjusted by the user during the analysis. A table with the default unit costs for each alternative is also provided. At this point, the user can modify the costs according to their experience and location. For all the rehabilitation alternatives the option of selecting a maintenance method to be performed within the life of the rehabilitation is provided. TxDOT (2006) recommends that the selected rehabilitation design strategy for flexible pavements should provide a minimum initial performance period of 8 years before an overlay is required. Therefore, the first maintenance is recommended to be performed 8 years after completing the

rehabilitation. The expected life of the maintenance method selected is used to determine the timing between maintenances during 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 3.2 by using the discount factor provided by the user and the accumulated time from the beginning of analysis. 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 the following:

$$Present\ Value = Future\ Value \times \left(\frac{1}{(1+r)^{n_k}} \right) \tag{3.2}$$

$$Total\ Present Value = Initial\ Cost + \sum Future Value \times \left(\frac{1}{(1+r)^{n_k}} \right) \tag{3.3}$$

where:

r = discount rate

n = number of years in the future when the cost will be incurred

3.2.5 Output

The results from all the alternatives based on LCCA are listed and rank ordered from the most economical to the most expensive. The color differentiation is still present at this point to distinguish between “recommended” and “less appropriate” alternatives. The final table displays the total present value, initial cost, salvage value and cost of routine maintenances for each alternative. The option of ranking the alternatives by the lowest initial cost or the lowest total present values cost is given to the user. The excel sheet provides enough cost information to allow the user to make decisions based on their own criteria. It is important to mention that the alternatives highlighted in green are recommended.

CHAPTER 4: CASE STUDY: INTERSECTION OF SH 155 AND SH 49 FORENSIC EVALUATION

4.1 BACKGROUND

The intersection of SH 49 and SH 155 is located in the Atlanta District. Figure 4.1 depicts the areal view of the intersection. This is a typical rural intersection with a 4-way light signalization consisting of flexible pavement only. The typical cross section is presented in Figure 4.2. The SH 155 pavement section consisted of a 2.0 in. AC over 11 in. of base, with the upper 8 in. lime treated. The SH 49 pavement section consisted of a 4.0 AC 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 predominant type of soil in the area is classified as Bowie fine sandy loam. This intersection was identified by district personnel of potential location due to the severity of distresses around the intersection area. The blue prints of these sections were provided by the district office.

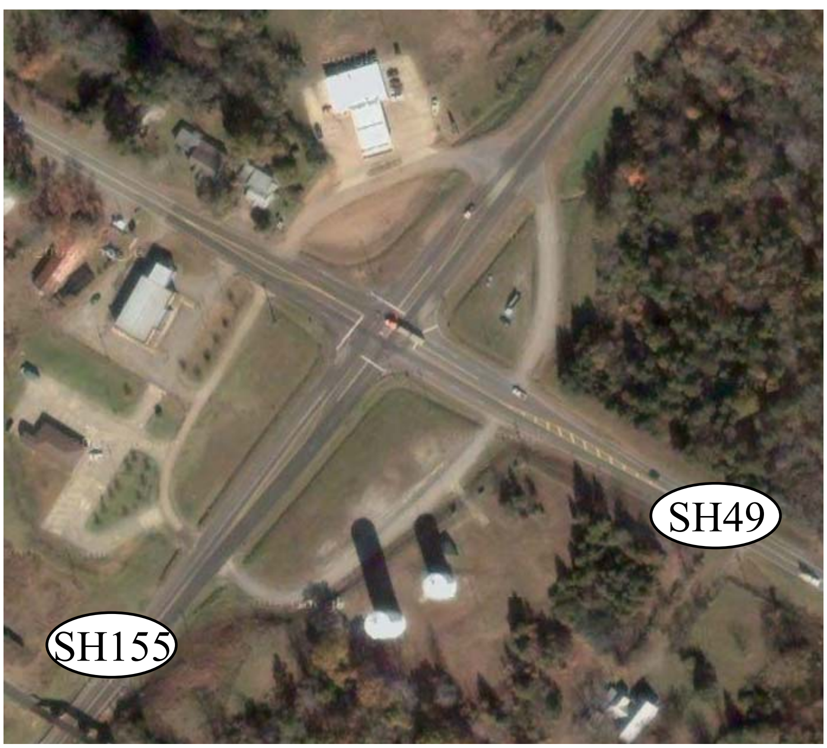
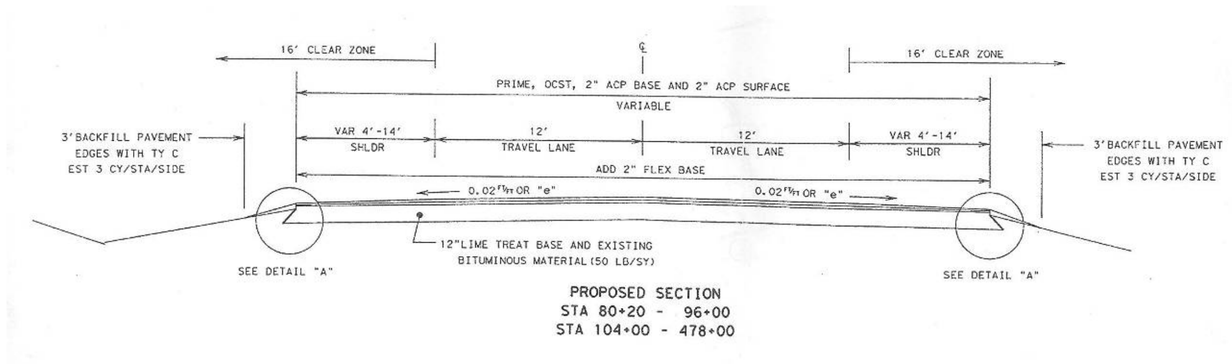
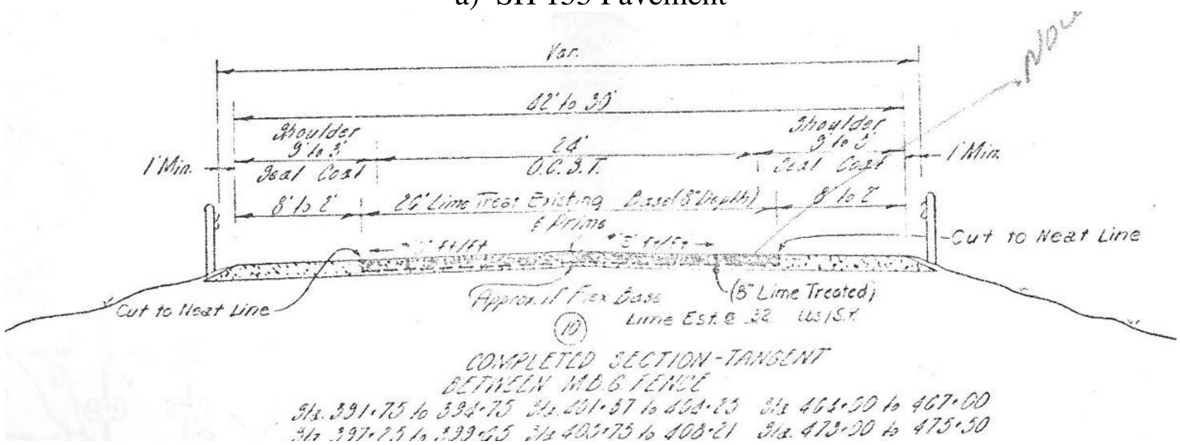


Figure 4.1: Aerial View of SH 155 and SH 49 Intersection.



a) SH 155 Pavement



b) SH 49 Pavement

Figure 4.2: Cross-sectional Pavement Design for SH 155 and SH 49

4.2 CONDITION SURVEY

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. A thorough inspection was carried out on all legs of the intersection. The primary distress 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, so it can be assumed that it might not be a mix problem, but maybe structural rutting. Figure 4.4 shows different views of the intersections along SH 155 with visible distresses. Loss of aggregate was evident on the rutted areas as well as some bleeding and flushing between wheel paths.

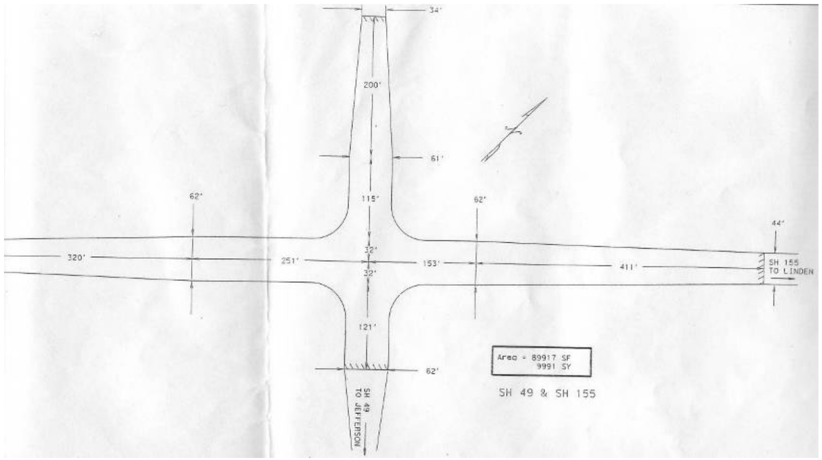


Figure 4.3: Geometry Design of SH 155 and SH 49 Intersection

Figure 4.4: Views of the Conditions of SH 155 and SH 49 Intersection.

As shown in Figure 4.5, the maximum rut depth was 0.5 in. on SH 155. This distress can be classified as Moderate Severity Structural Rutting. Another typical intersection 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 4.5: Rut Depth Measurement on SH 155.

The SH 49 inspection started 500 ft west of the intersection and extended 500 ft east of the intersection. The first 300 ft 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 at this point. Based on the cores, several lifts were added with 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, transversal cracking could be seen all the way along the 500 ft approach while severe block cracking was seen at the intersection. In some area, the severe block cracking contributed to generation of secondary distresses as depicted in Figure 4.6.

Figure 4.6: Cracking Resulting in Potholes on SH49.

4.2 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 away from the intersection, all in the approaching lanes. Three cores were extracted from each location, one per wheel-path and one in the middle of the wheel-paths, making it a total of 12 core extractions as marked in Figure 4.7.

Figure 4.7: Location of the Core Extractions.

Deflection data was collected using a Falling Weight Deflectometer (FWD). Both roads intersecting were evaluated using this method. Fwd data along SH 155 were collected 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 4.8a). The same was performed for SH 49, starting 500 ft west of the intersection (see Figure 4.8b). An air-launched Ground Penetrating Radar (GPR) was also used along these two roads.

a) SH155 b) SH49

Figure 4.8: FWD Collection on SH155 and SH49 Images

4.3 DATA ANALYSIS

4.3.1 Core Analysis

Figure 4.9 shows the coring process and a sample of the cores that were extracted. 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

Figure 4.9: Coring Process Images.

the retrieved aggregates from the oven to determine the gradation. Summaries of the analysis results and images of each core extracted are included in Appendix E.

The average thickness of each set of cores is plotted in relation with the distance from the intersection in Figure 4.10. The error bar indicates low variability in the thickness of 3 set of cores, except for the first set of cores extracted 500 ft north from the intersection on SH 155. A decrease in thickness as 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.

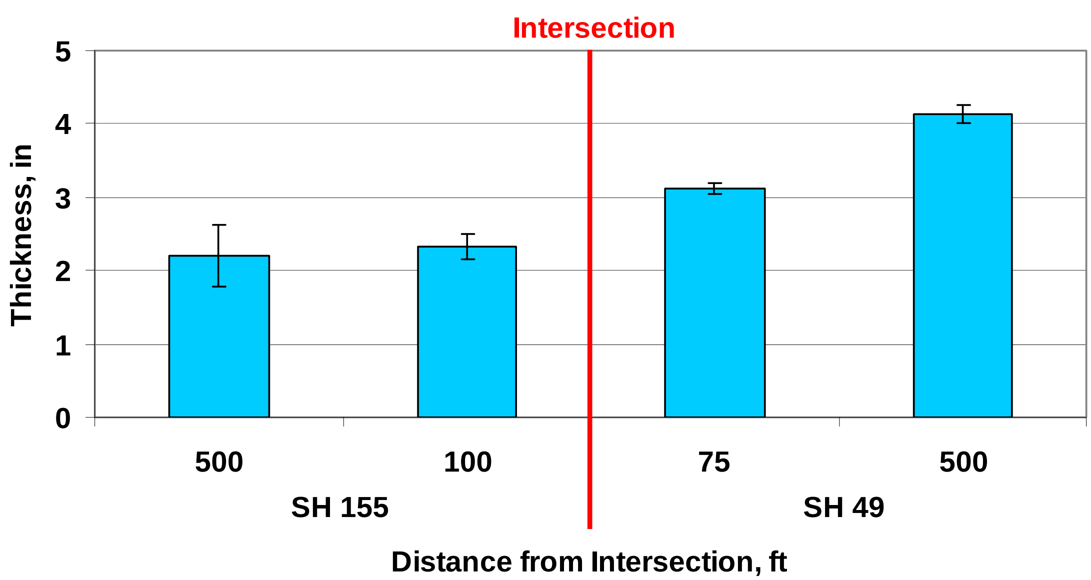


Figure 4.11: Core Average Thicknesses as Approaching the Intersection.

Figure 4.12 illustrate the decrease in air voids as approaching the intersection, which might be a result of the over densification of the surface layer produced by the slow moving loads while approaching the intersection. The high values of air voids 500 ft away from the intersection on SH 155 are because of the stripping of the materials.

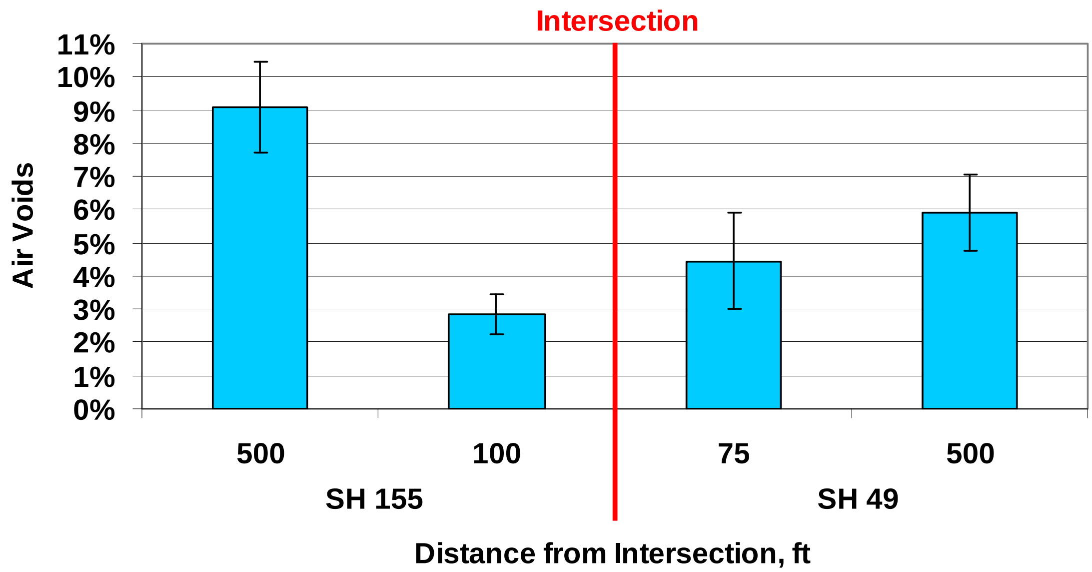


Figure 4.12: Core Average Air Voids as Approaching the Intersection.

The modulus trends as approaching the intersection are the opposite of the air voids for both roads as seen on Figure 4.13. The modulus was measured on every core using the V-meter, since the SH155 outer wheel path core at 500 ft away was damaged it affected the modulus readings from the V-meter and thereby the trend.

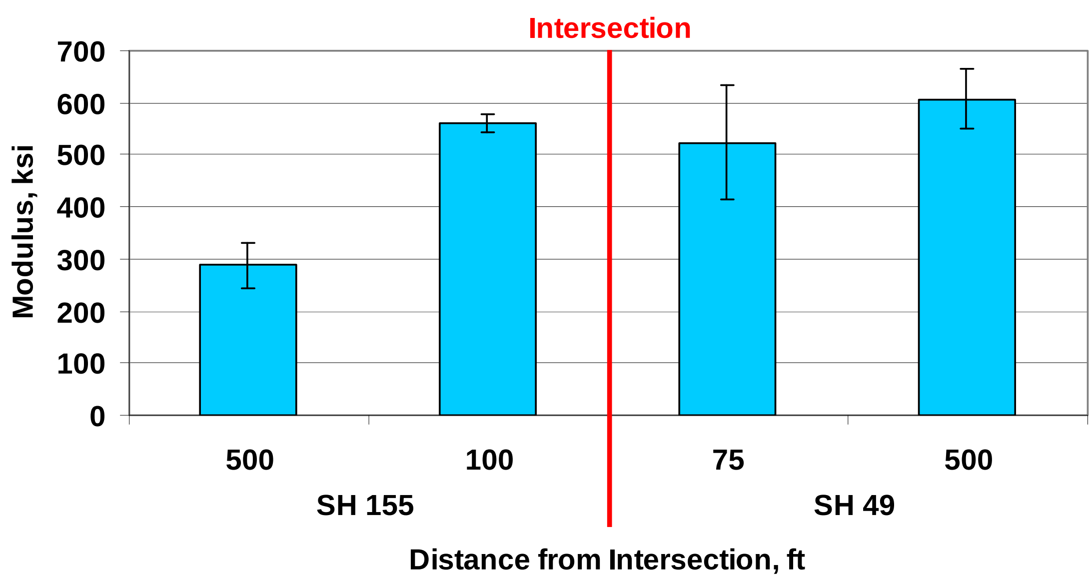


Figure 4.13: Core Average Design Modulus as Approaching the Intersection.

The variations in the asphalt contents of the cores are shown in Figure 4.14. Higher asphalt content close to the intersection may be a sign of aggregate loss caused either by aggregate segregation, and/or the high stresses under the breaking and turning of vehicles.

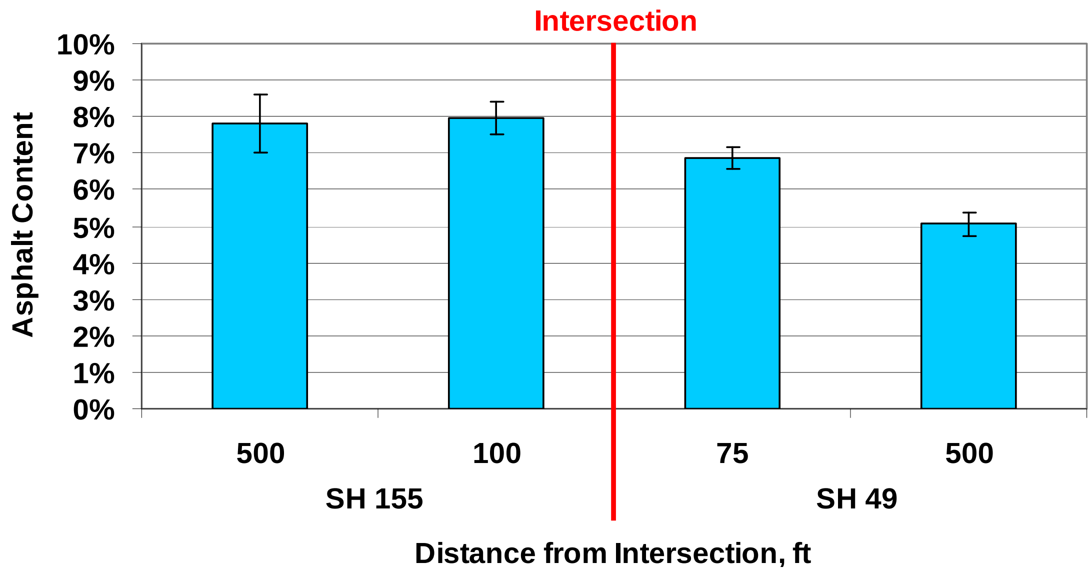


Figure 4.14: Core Asphalt Contents.

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 on Figure 4.15, but no reaction occurred on the first or fourth set of cores. A complete base core could only be extracted from the third location. Higher lime content was perceived for the third location.

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

Figure 4.15: Phenolphthalein Test for Lime on Base Material

4.3.2 FWD Analysis

Figure 4.16 illustrates the deflection results obtained from the FWD along the SH 155 section. Deflection values 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. Last 3 sensors did not detect a significant deflection, thereby can be assumed that the source of the problem does not go deeper than the base layer.

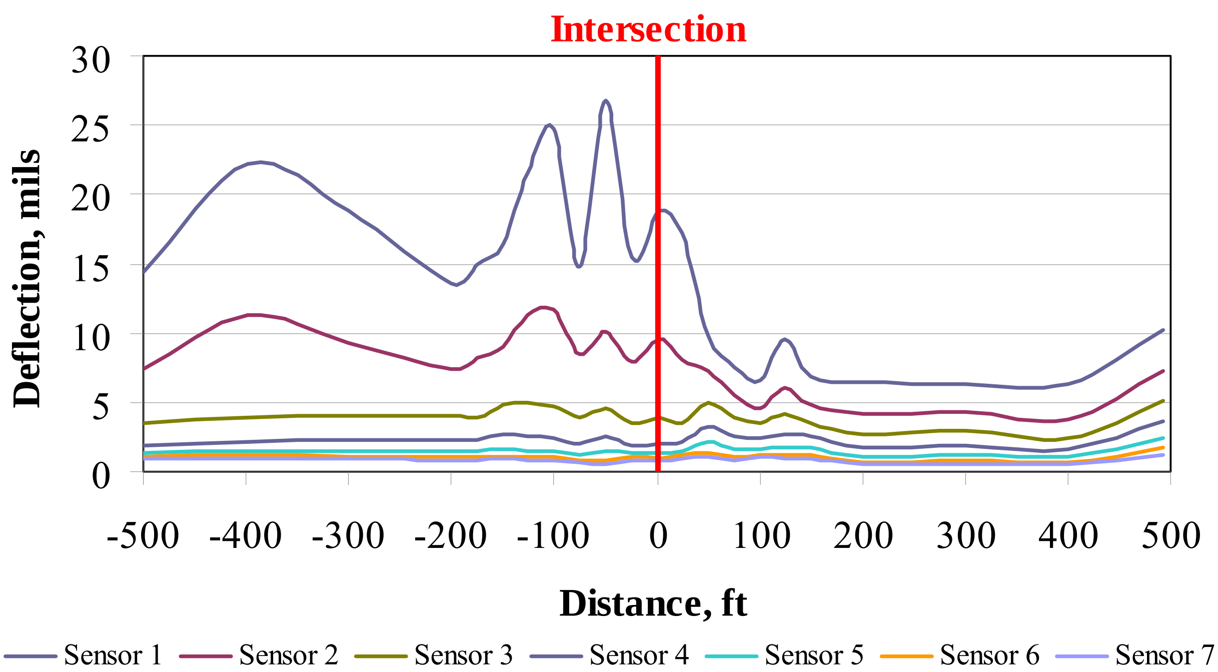


Figure 4.16: FWD Deflection Results on Southbound SH 155.

Figure 4.17 illustrates the deflections obtained from the SH 49 section. The first 200 ft with the different mix have a considerable lower deflection than the rest of the road. The increment in deflection after the first 200 ft remains constant until reaching the intersection, where a decrease in deflection is perceived. 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 deflection levels 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.

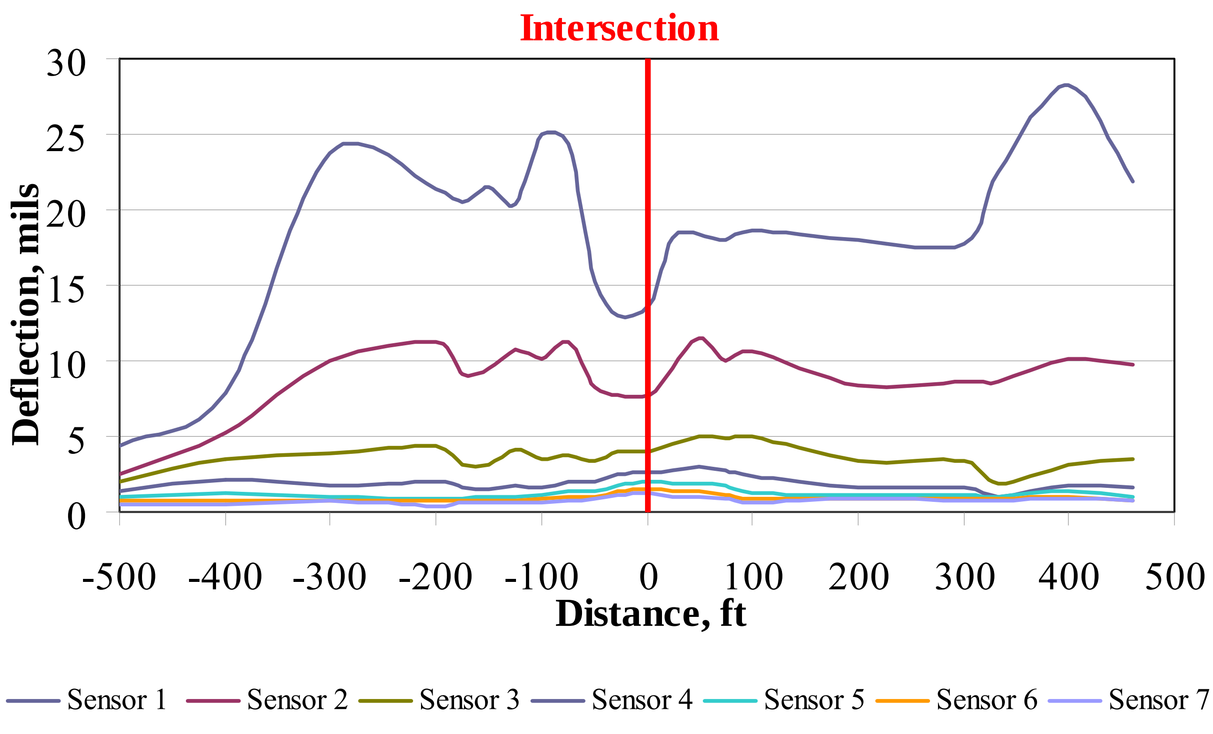


Figure 4.17: FWD Deflection Results on Eastbound SH 49.

4.3.3 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 4.18 is a sample of the data collected on SH 155 and SH 49 as approaching the intersection.

Figure 4.18- Sample of the GPR Data Close to the Intersection of FM155 and FM49.

Figure 4.19 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.

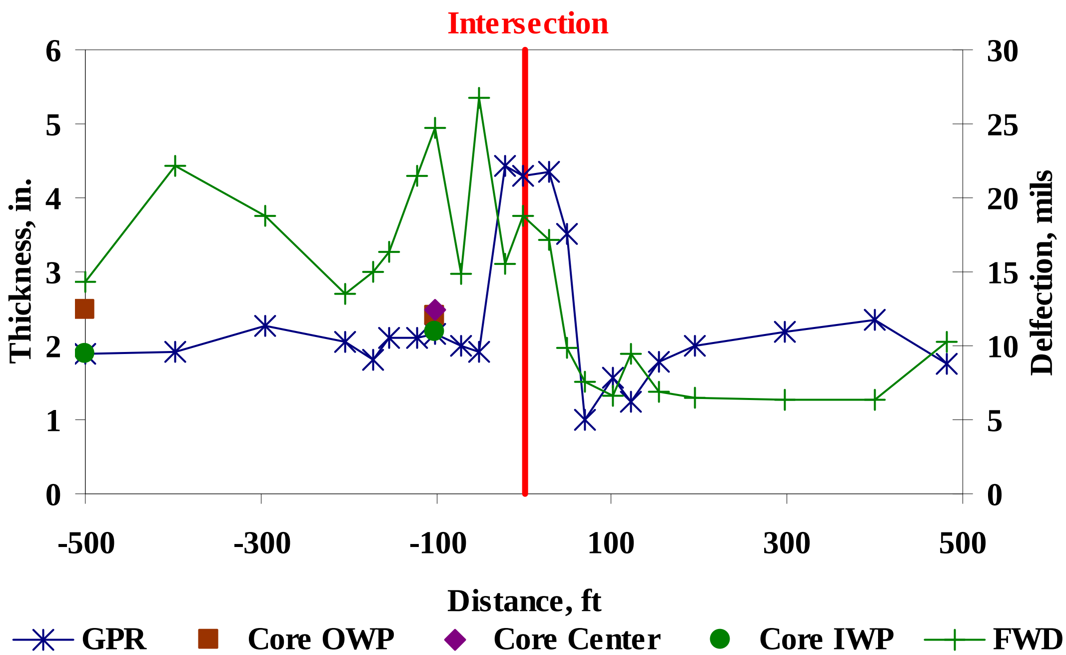


Figure 4.19: GPR, FWD and Cores on SH 155.

Similar results for SH 49 are illustrated in Figure 4.20. 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 5.0 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.

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.

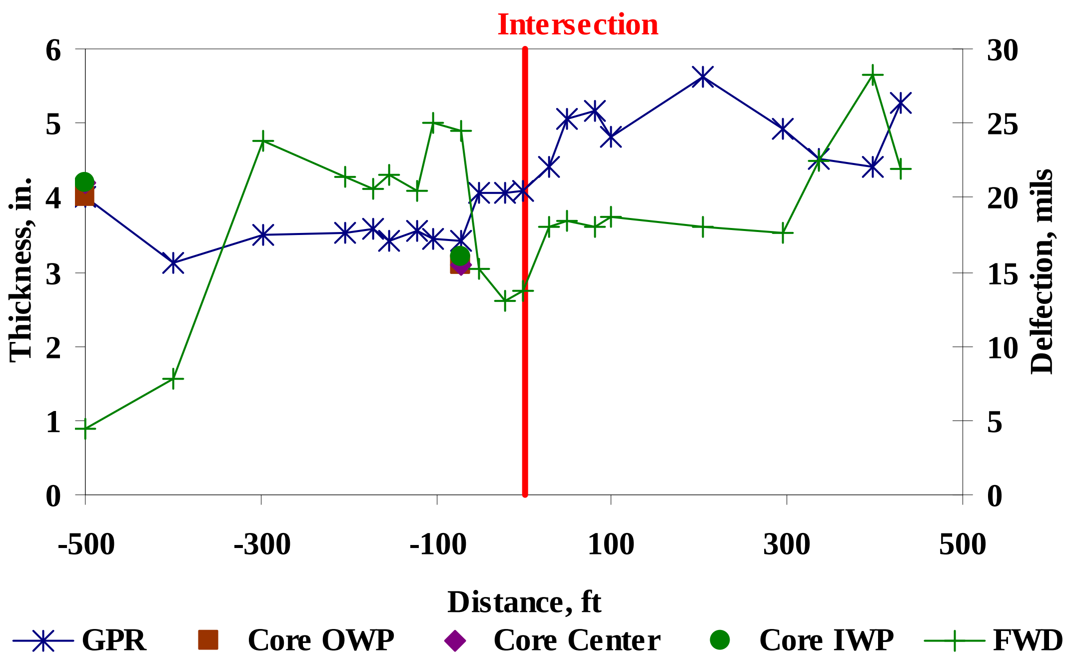


Figure 4.19: GPR, FWD and Cores on SH 49.

4.4 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. Deflection readings from FWD suggest that the problem does not come from a layer deeper than the Base. 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.

The intersection itself showed low levels of deflection, indicating that the base at this point is still in good condition. But still, the asphalt layer suffered from cracking, raveling and deformation.

CHAPTER 5: EXCEL SPREADSHEET ANALYSIS OF SH 155 AND SH 49 INTERSECTION

To demonstrate the utility of the Excel spreadsheet, the Atlanta District site described in the previous chapter is evaluated for the selection of a remediation strategy. The intersection is evaluated based on the field and laboratory studies carried out to identify the source of the problem. As soon as the source of the problem is identified, the spreadsheet can assist in selecting a list of alternatives that are suitable to repair the existing pavement. Based on an LCCA of all alternatives in the worksheet, the user can select the most cost-effective option or the one that fits best to the District's normal practices.

The spreadsheet consists of the following 6 sections

1. General Project Information
2. Analysis Options
3. Traffic Conditions
4. Evaluate Existing Pavement Condition
5. Repair Alternatives
6. Life Cycle Cost Analysis

The excel spreadsheet focuses on finding solutions for the specific source of the problem, in this case Base Moderate Structural Rutting. The area that suffers from this predominant distress should be calculated as an input parameter for the spreadsheet.

5.1 SECTION 1: GENERAL PROJECT INFORMATION

This section is intended for the documentation of the site. Figure 5.1 illustrates the initial input setup. The project name, district, county and roads intersecting need to be input, as well as the control, section and job numbers, if available. In this case the name of the project is "Intersection Repair" of "SH49 and SH155" in "Cass" County, in "Atlanta" District.

Strategies to Improve and Preserve Flexible Pavements at Intersections

Center for Transportation Infrastructure Systems (CTIS)

1. General Project Information

		Example
Project Name:	Intersection Repair	*Intersection Repair*
County:	Cass	*El Paso*
District:	Atlanta	*El Paso*
Roads:	SH49 and SH155	*SH 49 & SH 155*
Control:		*2*
Section:		*2*
Job:		*123*
User Name:	Carlos Solis	*John Smith*
Date:	11/29/2009	*8/9/2009*

Figure 5.1: Section No. 1 with General Project Information Input.

5.2 SECTION 2: ANALYSIS OPTIONS

The information provided in this section is used to calculate the costs and allow performing the LCCA. Figure 5.2 illustrates the required input. The first item on the list is the “Area to be Repaired,” which has to be input in square yards. This item is essential to calculate the Initial Cost that will be later used for obtaining the Present Value, and the Salvage and Total Present Values. Figure 5.3 shows the area selected to be repaired. An approximate area of 6,400 yd^2 was calculated for all the lanes that need to be repaired.

2. Analysis Options

		Example
Area to be Repaired (sq. yd.):	6400	*1600*
Beginning of Analysis Period:	2009	*2009*
Analysis Period (years):	30	*32 (Maximum of 60 yr.)*
Discount Rate (%):	4.00%	*4%*

Figure 5.2: Section No. 2 with Information about LCCA Analysis Options.

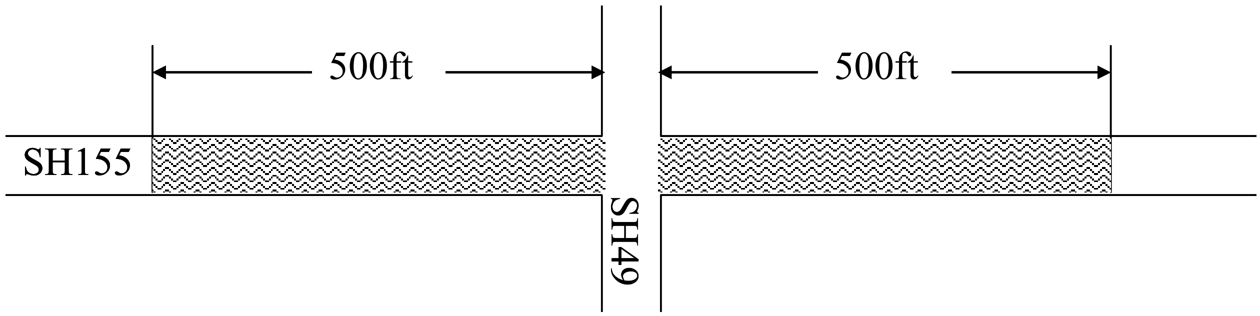


Figure 5.3: Schematic of the Recommended Area for Repair on SH 155.

The "Beginning of Analysis Period" is the year in which the construction is planned to start. The Analysis Period is used to compare the recommended alternatives under the same period by adding all the rehabilitation and maintenance costs required within that period for each alternative, and subtracting the Salvage Value if any. For this case a period of 30 years was selected to perform the analysis and comparison of the alternatives. Moreover, the Analysis Period is also used to compute the factor that brings the future costs to present worth. Likewise, the Discount Rate is utilized a (Equation 3.2) for finding the Present Value of the amount to be spent in the future, and it is usually around 4%.

5.3 SECTION 3: TRAFFIC CONDITIONS

The information obtained from this section is used to classify the traffic volume of the intersection. Although the traffic counts for this site were not collected it was indeed known to be a low volume intersection. The AADT values at this point were assumed to proceed with the evaluation as shown in Figure 5.4. A truck Percentage of 50 was selected assuming that both single and multiple unit trucks traffic the intersections. A truck factor of 0.52 was selected from Table 3.2 following the assumption that all classes of trucks will be traveling the intersection. A conservative lane distribution factor of 1.0 was chosen. By utilizing these assumptions the Yearly ESALs were kept below the limit of 25,000 for low volume roads.

3. Traffic Conditions

		Recommendations
AADT Construction Year (total for all directions):	400	Be sure to add the AADT from both roads.
AADT Projected at the End of Analysis Period:	600	Be sure to add the AADT from both roads.
Combination Trucks as Percentage of AADT (%):	50.00%	
Truck Factor:	0.52	0.52 recommended for all truck types by AI (1991)
Lane Distribution Factor:	1.00	1.0 recommended by VDOT for rural intersections
Daily ESAL:	23725.00	Low Volume Limit of 25,000 Yearly ESAL

Tables to select different truck and lane distribution factors, and truck percentages are provided in the following link: ESAL Tables

Figure 5.4: Traffic Conditions Input Parameters.

5.4 SECTION 4: EVALUATE EXISTING PAVEMENT CONDITION

The results from the site investigation are introduced in the program at this time, including the layer identified as the source of the problem, and selecting the predominant distress and its severity. The layer selection options are “Asphalt”, “Base”, and “Subgrade”, while the distress selection options are those described in Section 3.2.2.1. Finally for this section the severity of the distress is to be selected among “Low”, “Moderate”, “High”, or “No Severity”. The last severity option is only for those distresses which are not subcategorized by severity.

Figure 5.5 illustrates the 3 selection boxes filled with the predominant distress. Base structural rutting of moderate severity was the identified predominant distress at the intersection. While the same distress was continuous along the 1000 ft section (both directions) of SH 155, SH 49 suffered mostly of cracking for the rest of the analyzed section. However, as structural rutting was the most severe problem, the selection process should first aim to correct it.

4. Evaluate Existing Pavement Condition

Distressed Layer:	Base
Predominant Distress:	Structural Rutting
Distress Severity:	Moderate

Figure 5.5: Section No. 4 for the Evaluation of the Existing Pavement.

5.5 SECTION 5: REPAIR ALTERNATIVES

The purpose of this section is to present all the possible repair alternatives extracted from the matrix of solutions from Chapter 2 based on the identified predominant distress provided by the users in Section 4. This section contains two tables. The first table (Figure 5.6a) presents all the possible maintenance and rehabilitation alternatives for the problem obtained from the matrix of solutions. The "Recommended" and "May be Appropriate" alternatives are differentiated by highlighting the first ones in green and the second ones in yellow (a color legend is provided). The same table provides default values for materials and construction costs, and life expectancies for each alternative, which can be adjusted by the user, based on her/his experience or knowledge. These default values, which were collected form the literature and are provided in the "Cost & Life" sheet.

The second table illustrated on Figure 5.6b list the rehabilitation alternatives separated from the maintenance alternatives, and allows the user to select from a box list of maintenance method to be performed within the life of each of the rehabilitation alternatives throughout the analysis period. The maintenance alternatives are the same as those in the matrix of solutions. This table also provides default values for materials and construction costs, and life expectancies of each maintenance alternative selected, also allowing the user to modify them. For the sake of comparing all the alternatives under the same conditions microsurfacing was selected for all alternatives in this example.

5. Repair Alternatives

(green)	Recommended Alternatives
(yellow)	May Be Appropriate Alternatives

Possible Alternatives			
Alternatives	Costs, $/sq. yd.		Life
	Materials	Construction	Expectancy, yr
Cold In-Place Recycling	$1.50	$2.50	8
HMA & RAP Overlay	$1.50	$2.30	15
Hot Mix Overlay	$4.00	$3.00	15
HMA & Recycled Asphalt Shingles (RAS) Overlay	$1.30	$2.00	10
PCC Overlay (Thick)	$8.00	$8.00	25
Full-Depth Reclamation	$5.00	$5.30	20
Roller Compacted Concrete	$10.00	$10.00	30
Full Depth Reclamation with Stabilization	$5.90	$7.00	20

a) All Alternative Costs and Life Expectancies

Select Maintenance for Rehabilitation Alternatives					
Rehabilitation	Select	Maintenance Costs, $/sq. yd.		Life	Time for First
	Maintenance	Materials	Construction	Expectancy, yr	Maintenance, yr
Cold In-Place Recycling	Microsurfacing	$2.00	$1.30	7	8
HMA & RAP Overlay	Microsurfacing	$2.00	$1.30	7	8
Hot Mix Overlay	Microsurfacing	$2.00	$1.30	7	8
HMA & Recycled Asphalt Shingles (RAS) Overlay	Microsurfacing	$2.00	$1.30	7	8
PCC Overlay (Thick)	Microsurfacing	$2.00	$1.30	7	8
Full-Depth Reclamation	Microsurfacing	$2.00	$1.30	7	8
Roller Compacted Concrete	Microsurfacing	$2.00	$1.30	7	8
Full Depth Reclamation with Stabilization	Microsurfacing	$2.00	$1.30	7	8

b) Maintenance Method Selection for Rehabilitation Alternatives.

Figure 5.6: Section 5 Tables for Costs and Life Expectancies.

5.6 SECTION 6: LIFE CYCLE COST ANALYSIS

The life cycle cost analysis of all the alternatives takes place in this section. The costs of all alternatives are compared under the same analysis period. The option of ranking the alternatives by "Initial Cost" or "Total Present Value" is given through a selection box. As seen on Figure 5.7, the alternatives maintain the color label to differentiate between the recommended and may be appropriate alternatives. Full Depth Reclamation (FDR) with or without stabilization are the most appropriate alternatives based on performance. The performance is uncertain for the rest of the alternatives in the list. HMA and RAP Overlay is the most economical alternative, although it is not fully recommended, as highlighted in yellow. At this point the district personnel experience takes and important role in the decision making.

6. Life Cycle Cost Analysis

Rank by:

Total Present Value

Rank	Alternative	Total Present Value	Initial Cost	Routine Maintenance
1	HMA & RAP Overlay	$61,825	$24,320	$21,120
2	Cold In-Place Recycling	$65,988	$25,600	$21,120
3	HMA & Recycled Asphalt Shingles (RAS) Overlay	$77,927	$21,120	$21,120
4	Hot Mix Overlay	$93,677	$44,800	$21,120
5	Full-Depth Reclamation	$120,045	$65,920	$21,120
6	Full Depth Reclamation with Stabilization	$141,714	$82,560	$21,120
7	PCC Overlay (Thick)	$151,626	$102,400	$21,120
8	Roller Compacted Concrete	$170,843	$128,000	$21,120

Figure 5.7: Section No. 6 with Ranked Cost Results.

The present value costs of the alternatives are compared in a graph created by the spreadsheet as seen on Figure 5.8. The values for each alternative are equivalent to the summation of present value costs of all the activities within the same analysis period. This graph allows the user to visually compare the alternatives and identify the most economical alternative over the analysis period.

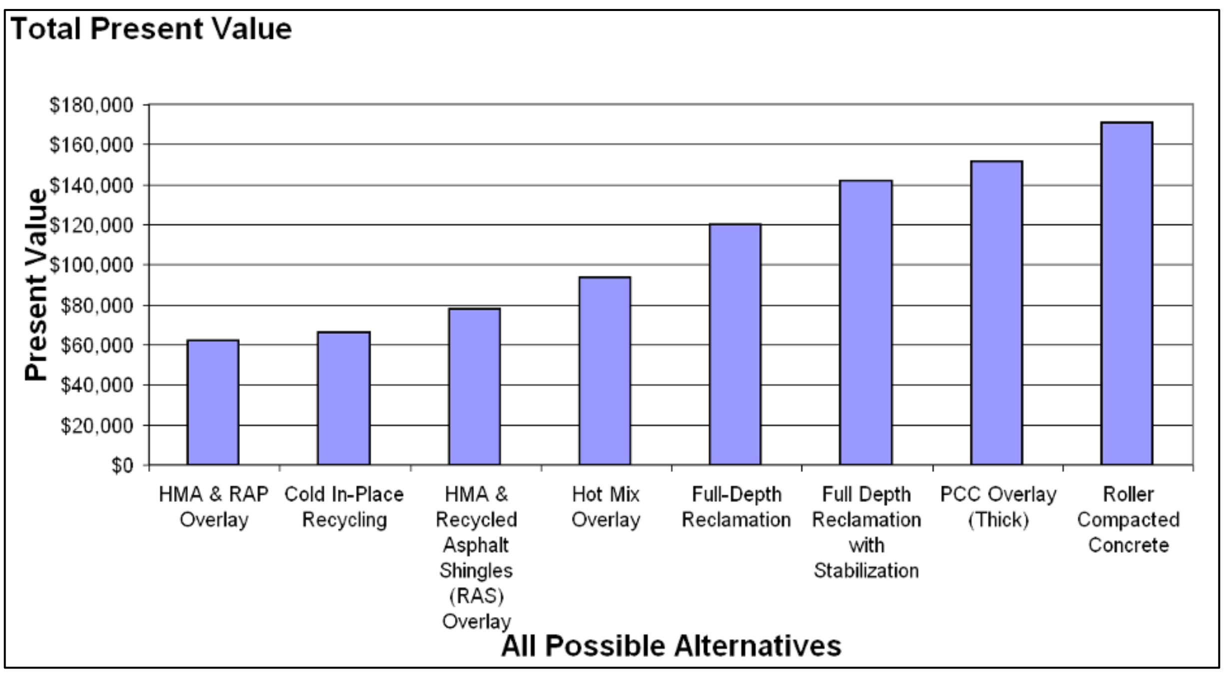


Figure 5.8: All Alternative Present Value Comparison Graph.

Figure 5.9 is a chronological plot of the costs that are expected to be incurred on the intersection for the length of the analysis period for the most economical alternative, in this case HMA and RAP Overlay and its respective microsurfacing maintenance selected in Section 5. The green bars represent rehabilitation and maintenance costs while the red bar represents the salvage value at the end of the analysis period. The tallest bars indicate the rehabilitation expense which occur every 15 years, the life expectancy of HMA and RAP Overlay. The short green bars are the microsurfacing expenses done within the life of the rehabilitation.

The graph on Figure 5.10 is similar to the previous graph, but gives the users the option of selecting any of the other alternatives from a box list to visually compare it with the most economical one. Full Depth Reclamation is selected to be compared with the most economical, since it is has the lowest cost from the two recommended alternatives. At a total present value of $120,000 for a period of 30 years, Full-Depth Reclamation is recommended as it is the most economical of the most appropriate alternatives.

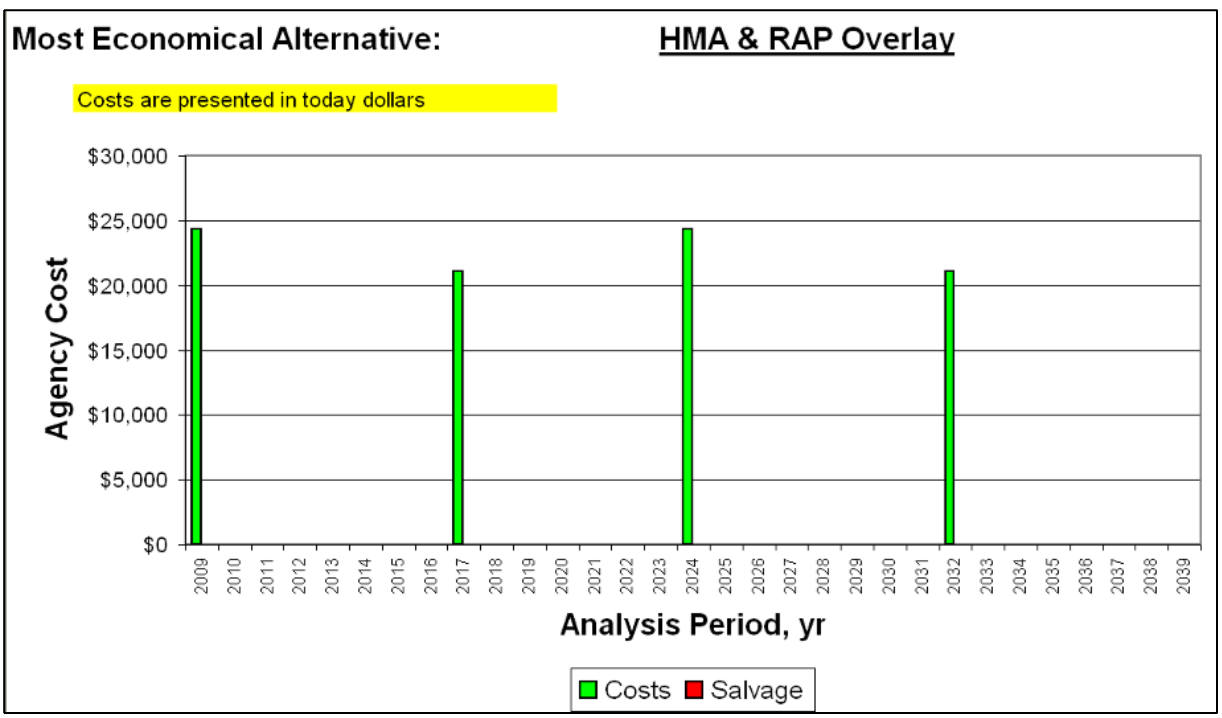


Figure 5.9: LCCA Plot for the Most Economical Alternative.

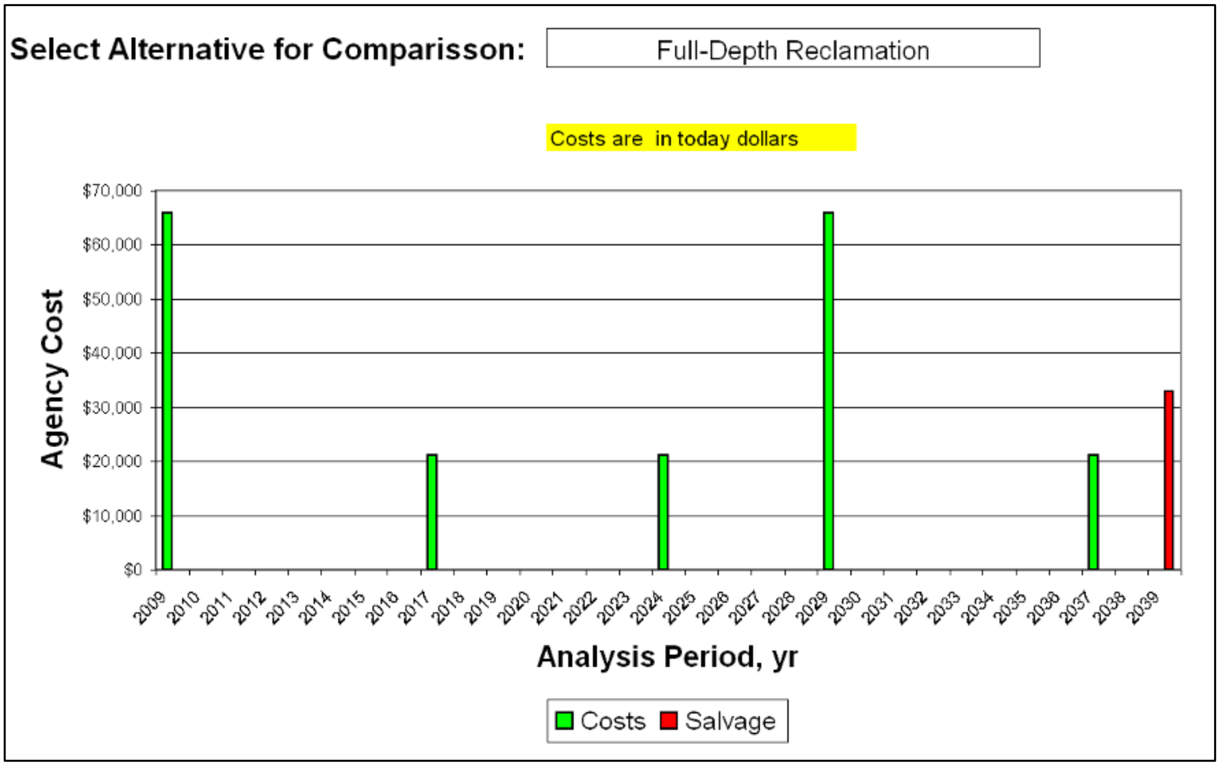


Figure 5.10: LCCA Plot for Full Depth Reclamation.

The analysis just performed was focused in resolving the base structural problem on SH 155 only. For the rest of the intersection, on SH 49, an overlay is recommended. The analysis on SH 49 provided clues suggesting that the problem was either bad construction practices or design. The base at this section is still in good conditions, and should be left as is. It is recommended that the asphalt layer be completely removed and replaced.

CHAPTER 6: SUMMARY AND CONCLUSIONS

6.1 SUMMARY

The literature review describes 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. The characteristics and methodology of TxDOT's preferred flexible pavement design software FPS-19, and AASHTO's DARWin were described and their limitations were pointed out. Different cost analysis methods were compared and discussed, and the Life-Cycle cost analysis as per the FHWA methodology is described.

A matrix that links probable distresses and the appropriate remediation resourced from the literature review was created. The matrix aims 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 matrix provides 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 pavement agencies was 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 matrix 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.

A questionnaire was developed and distributed to all Texas districts. The questionnaire 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.

An easy-to-use Microsoft Excel spreadsheet was created to incorporate the knowledge gained as a preliminary guide for the selection of remediation strategies. The excel sheet represents a systematic implementation of the matrix of solutions, which is 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 alternative.

A thorough study of the intersection between SH 155 and SH 49 was performed. Visual, destructive and non-destructive analyses were performed to assess the condition of the pavement at the intersection. The evidence from the visual condition survey on SH 155 suggests that the base layer was the source of rutting. The GPR results corroborated the same assumption by showing a consistency in the thickness of the asphalt layer. Deflection readings from FWD suggested that the problem did not come from a layer deeper than the base. The predominant distress for SH 155 was classified as Moderate Structural Rutting of the base. High severity block cracking was the most visible distress on SH 49. Aging of the asphalt or wrong binder selection could have been the causes of the failure with base being in good condition. Severe block cracking might have been the source of the high deflection readings by FWD.

Finally, as a preliminary utilization of the Excel spreadsheet at the intersection of SH 155 and SH 49 was evaluated after having identified the source of the problem for the selection of a remediation strategy. The spreadsheet performed LCCA for a list of alternatives extracted from the matrix of solutions for the users to compare. At a Total Present Value of $120,000 for a period of 30 years, Full-Depth Reclamation is recommended as it is the most economical of the trustable alternatives.

6.2 RECOMMENDATIONS AND FUTURE WORK

Five sites have been visited so far and the results from each site are being documented. Knowledge gained from these sites will be used in the development of the final guideline. Based on the experience gained during our visits to the first set of sites, a checklist that details the information that should be collected and gathered for a more comprehensive analysis is presented in Appendix F. This list will serve as a guide for future sites. The list covers data such as traffic, geometry, condition survey, field testing such as FWD and coring, and laboratory testing.

The project will continue developing a final guideline. The information will be incorporated in a concise but attractive document that can be used as a guidebook by TxDOT personnel. An electronic version of the guide will also be provided with appropriate hyperlinks to definitions, relevant TxDOT specifications, step-by-step procedures and other web-pages that provide additional information to TxDOT personnel.

The following stages of the project will incorporate the literature and empirical knowledge gained with the expertise of the engineers that are experience with intersection remediation. The knowledge has been collected by thorough interview with districts experts and is in the process of summarization. An expert system will be developed and will serve as a step-by-step guidance on the process of designing the optimum solution. The expert system will have a knowledge base that will include all the factors that will be developed in the guidelines to reach the final decision.

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APPENDIX A: TXDOT RESEARCH PROJECT 0-5566 QUESTIONNAIRE

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

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 loose 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____________________

(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 QUESTIONNAIRE

Table B.1: 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 B.2: 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 B.3: 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 B.4: 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 B.5: 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 B.6: 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 B.7: 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 B.8: 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 B.9: 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 B.10: 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: EXCEL SPREADSHEET INTERFACE MANUAL

The Intersection Repair Method Selection Spreadsheet was developed in Microsoft Excel in order to identify the proper remediation methods for flexible pavements at intersections and to perform the Life Cycle Cost Analysis (LCCA) to obtain the most economical alternative. Namely, this program is focused on helping the user's decision-making in an interactive form.

The spreadsheet requires no installation, and since it doesn't contain several macros no extra activities have to be carried out. The software may be used for the following purposes:

- Finding the appropriate repair alternatives for a given flexible pavement structure and traffic loading scenario.
- LCCA variables determination such as Initial Cost, Present Value, Total Present Value and Salvage Value.
- LCCA graphs for comparison of the recommended repair alternatives.
- Daily ESAL determination based on the average AADT (Average Annual Daily Traffic) throughout the extension of the analysis period, the correlation for the number of 18 kip (80 kN0 single-axle load applications per truck, and the percentage of traffic traveling per lane on each direction.

The spreadsheet consists of the following 6 sections:

1. General Project Information
2. Analysis Options
3. Traffic Conditions
4. Evaluate Existing Pavement Condition
5. Repair Alternatives
6. Life Cycle Cost Analysis

C.1 SECTION 1: GENERAL PROJECT INFORMATION

This section is mainly for the documentation of the site. Figure C.1 shows the initial section, the empty boxes are supposed to be filled with the project information, such as project

name, county, district, roads, control, section, job, user name, and date of the analysis. At the right side of each box an example is provided to orientate the user.

Strategies to Improve and Preserve Flexible Pavements at Intersections

1. General Project Information

		Example
Project Name:		*Intersection Repair on SH 49*
County:		*El Paso*
District:		*El Paso*
Roads:		*SH 49 & SH 155*
Control:		*2*
Section:		*2*
Job:		*123*
User Name:		*John Smith*
Date:		*8/9/2009*

Figure C.1 – Section No. 1 General Project Information.

C.2 SECTION 2: ANALYSIS OPTIONS

The information provided in this section is used to calculate the costs and allow performing the LCCA. The first item on the list is the Area to be Repaired which has to be given in square yards. This item is essential to calculate the Initial Cost that will be later used for obtaining the Present Value, and so the Salvage and Total Present Values. The Beginning of Analysis Period is the year in which the construction is planned to start, and it will only be employ on the comparison LCCA graphs. The Analysis Period is used to economically compare the recommended alternatives under the same period by adding up all the rehabilitation and maintenance costs required within that period for each alternative, and subtracting the Salvage Value if any. Moreover, the Analysis Period is also used to compute the factor that brings the future costs to present worth. Likewise, the Discount Rate is utilized in the same formula for finding the Present Value of the amount to be spent in the future, and it is usually around 4%. Figure C.2 shows an example of Section 2 filled with typical values.

2. Analysis Options

Area to be Repaired (sq. yd.):	1500	1600
Beginning of Analysis Period:	2010	2009
Analysis Period (years):	25	32
Discount Rate (%):	4.00%	4%

Figure C.2 – Section No. 2 with Analysis Options Input.

C.3 SECTION 3: TRAFFIC CONDITIONS

The spreadsheet represents an economization tool by recommending low cost alternatives that would perform at their best on low volume roads. The information obtained from this section is used to classify the traffic volume of the intersection.

The classification is based on a differentiating value of 150 daily ESALs. If the traffic is under 150 daily ESALs then the intersection is considered as low volume and the low cost alternatives will be considered in the evaluation, otherwise the intersection will be considered as high volume and the recommended alternatives will be the typical for high volume roads. Figure C.3 illustrates the traffic conditions input section, where 5 boxes have to be filled to calculate the daily ESALs, or if available just directly input the daily ESALs. The first box is for the Average Annual Daily Traffic (AADT) during the year of construction, while the second box is for the estimated AADT at the end of the analysis period, these two values with the purpose of calculating an average AADT during the extension of the analysis period. The Combination of Trucks as Percentage of AADT is necessary to calculate the number of heavy vehicles and then be multiplied by the Truck Factor which is the correlation for the number of 18 kip (80 kN) single-axle load applications per truck. Finally the Lane Distribution Factor (LDF) represents the percent of traffic traveling per lane on each direction, since rural roads consist of one lane per direction a value of 1.0 is recommended. Equation C.1 is used by the spreadsheet to calculate the daily ESALs.

$$Daily\ \ ESAL = \left(\frac{AADT_i + AADT_f}{2} \right) (T)(T_f)(L)(0.5) \qquad \text{(E.1)}$$

where:

AADTi = Average Annual Daily Traffic during construction year

AADTf = Average Annual Daily Traffic projected at the end of analysis period

T = Truck Percentage

Tf = Truck Factor

L = Lane Distribution Factor

3. Traffic Conditions

AADT Construction Year (total for all directions):	500
AADT Projected at the End of Analysis Period:	700
Combination Trucks as Percentage of AADT (%):	80.00%
Truck Factor:	0.52
Lane Distribution Factor:	1.00
Daily ESAL:	124.80

Figure C.3 – Section No. 3 with Traffic Conditions Input.

C.4 SECTION 4: EVALUATE EXISTING PAVEMENT CONDITION

Section 4 is to identify the problem based on visual identification, classification and severity of the distresses and the failing layer of the pavement structure. It consists of three selection boxes that have to be filled in order each time.

4. Evaluate Existing Pavement Condition

Distressed Layer:	Asphalt Layer
Predominant Distress:	Surface Rutting
Distress Severity:	Moderate

Figure C.4 – Section No. 4 for the Evaluation of the Existing Pavement.

C.5 SECTION 5: REPAIR ALTERNATIVES

This section provides two tables. The first table presents all the possible repair alternatives for the problem identified (in this case based on the answers from Figure C.4), both maintenance and rehabilitation options. The “Recommended” and “May be Appropriate” are

differentiated by highlighting the first ones in green and the second ones in yellow (a color legend is provided). The same table provides default values for materials and construction costs, and life expectancies for each alternative, which might be adjusted by the user's own experience or knowledge. All these default values were collected from the literature and gathered together in the "Cost & Life" sheet that will be described shortly.

5. Repair Alternatives

Recommended Alternatives (green)
May Be Appropriate Alternatives (yellow)

Possible Alternatives			
Alternatives	Costs, $/sq. yd.		Life Expectancy, yr
	Materials	Construction	
Microsurfacing	$0.80	$0.40	4
Crack Seal	$0.50	$0.20	4
Sand Seal*	$0.70	$0.40	4
Slurry Seal*	$0.70	$0.30	4
Chip Seals	$0.90	$0.50	4
Surface Treatment	$0.90	$0.40	4
Hot In-Place Recycling	$1.00	$3.00	10
Cold In-Place Recycling	$1.00	$2.50	10
HMA & RAP Overlay	$2.00	$2.30	10
Hot Mix Overlay	$2.00	$3.00	10
HMA & Recycled Asphalt Shingles (RAS) Overlay	$2.00	$1.50	10
PCC Overlay (Thick)	$3.00	$3.00	20
Full-Depth Reclamation	$3.00	$4.00	15

Figure C.5 – Section No. 5 with all the Possible Alternatives.

The second table separates the rehabilitation alternatives from the maintenance alternatives, allowing the user to select from a box a maintenance method to be performed within the life of each of the rehabilitation alternatives. The user might choose the same, different or not maintenance at all for each of rehabilitation treatments. This table also provides default values for materials and construction costs, and life expectancies of each maintenance alternative selected, also allowing the user to modify such values.

Select Maintenance for Rehabilitation Alternatives				
Rehabilitation	Select Maintenance	Maintenance Costs, $/sq. yd.		Life Expectancy, yr
		Materials	Construction	
Hot In-Place Recycling	Microsurfacing	$0.80	$0.40	4
Cold In-Place Recycling	Microsurfacing	$0.80	$0.40	4
HMA & RAP Overlay	Microsurfacing	$0.80	$0.40	4
Hot Mix Overlay	Microsurfacing	$0.80	$0.40	4
HMA & Recycled Asphalt Shingles (RAS) Overlay	Microsurfacing	$0.80	$0.40	4
PCC Overlay (Thick)	Microsurfacing	$0.80	$0.40	4
Full-Depth Reclamation	Microsurfacing	$0.80	$0.40	4

Figure C.6 – Section No. 5 Table for Maintenance Method Selection.

C.6 SECTION 6: LIFE CYCLE COST ANALYSIS

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 pavement design on the future cost of 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 user cost is not readily available. Therefore user's costs (user delay costs, vehicle operating costs, and crash costs) and the construction activity timing were omitted from the analysis.

The first step is to establish the alternatives that will accomplish the structural and performance objectives of the project. The analysis period is essential for the LCCA to compare the recommended alternatives economically. In addition, it is necessary that all alternatives are under the same analysis period. The activity timing has to be determined for the initial and future activities involving on 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. For all the rehabilitation alternatives the option of selecting a maintenance method to be performed within the life of the rehabilitation is provided. TxDOT (2006) recommends that the selected rehabilitation design strategy for flexible pavements should provide a minimum initial performance period of 8 years before an overlay is required. Therefore, when comparing rehabilitation alternatives with maintenance in between a period of 8 years is recommended

before the first maintenance. The expected life of the maintenance method selected is used to determine the timing between maintenances under the analysis period. 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 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 C.2 by using the discount factor. 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 the following:

$$Present\ Value = Future\ Value \times \left(\frac{1}{(1+r)^{n_k}} \right) \tag{C.2}$$

$$Total\ Present Value = Initial\ Cost + \sum Future Value \times \left(\frac{1}{(1+r)^{n_k}} \right) \tag{C.3}$$

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.

The table in Figure C.7 displays the results of the Life Cycle Cost Analysis, Total Present Values, Initial Costs, and Routine Maintenance Costs within the analysis period. The option of ranking the alternatives by "Initial Cost" or "Total Present Value" is given by a selection box. The alternatives maintain the color label to differentiate between the recommended and may be appropriate alternatives.

Total Present Value list contains the addition of the discounted future values, including rehabilitations and maintenances throughout the analysis period, and the subtraction of the Salvage Value they might have left. Meanwhile, the Initial Cost and Routine Maintenance lists values are not adjusted at all.

6. Life Cycle Cost Analysis

Rank by: Total Present Value

Rank	Alternative	Total Present Value, $	Initial Cost, $	Routine Maintenance, $
1	Crack Seal	$4,525	$1,050	$1,050
2	Slurry Seal*	$6,464	$1,500	$1,500
3	Sand Seal*	$7,110	$1,650	$1,650
4	Microsurfacing	$7,757	$1,800	$1,800
5	Surface Treatment	$8,403	$1,950	$1,950
6	Chip Seals	$9,049	$2,100	$2,100
7	Cold In-Place Recycling	$15,692	$5,250	$1,800
8	HMA & Recycled Asphalt Shingles (RAS) Overlay	$15,692	$5,250	$1,800
9	PCC Overlay (Thick)	$16,217	$9,000	$1,800
10	Hot In-Place Recycling	$17,150	$6,000	$1,800
11	HMA & RAP Overlay	$18,025	$6,450	$1,800
12	Hot Mix Overlay	$20,067	$7,500	$1,800
13	Full-Depth Reclamation	$20,580	$10,500	$1,800

Figure C.7 – Section No. 6 with Ranked Cost Results.

Furthermore, all the alternatives are compared based on their Present Value in a graph on Figure C.8. Again, the values for cost are adjusted to present value by using the discount rate and the analysis period.

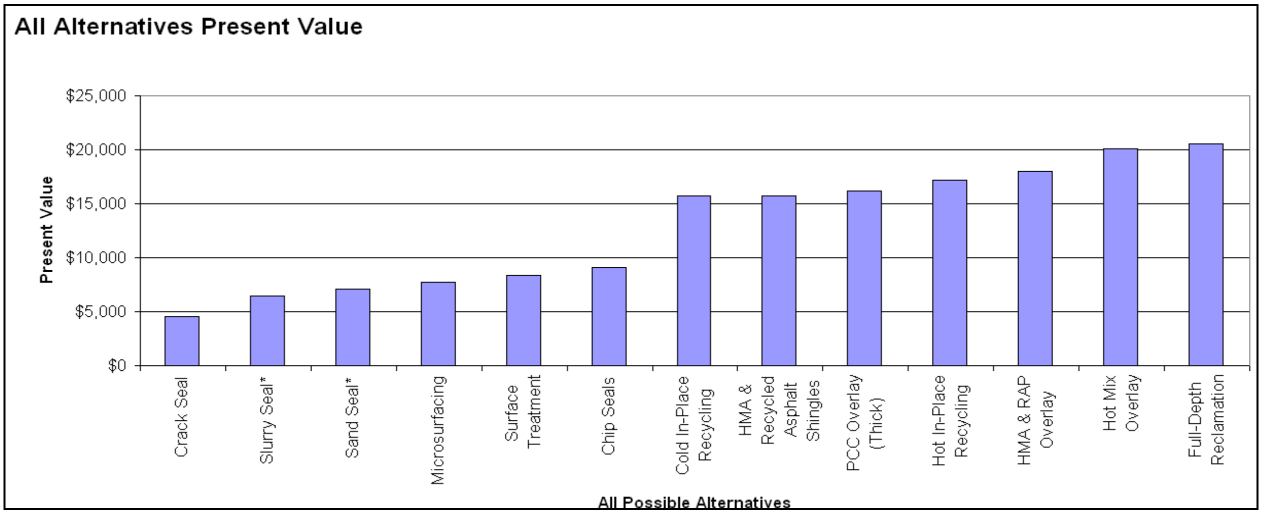


Figure C.8 – Section No. 6 All Alternative Present Value Comparison Graph.

The graph on Figure C.9 plots the costs as well as the activity timing throughout the analysis period of the most economical remediation alternative; the green values represent rehabilitation and maintenance costs while the red bar represents the salvage value of the construction at the end of the analysis period.

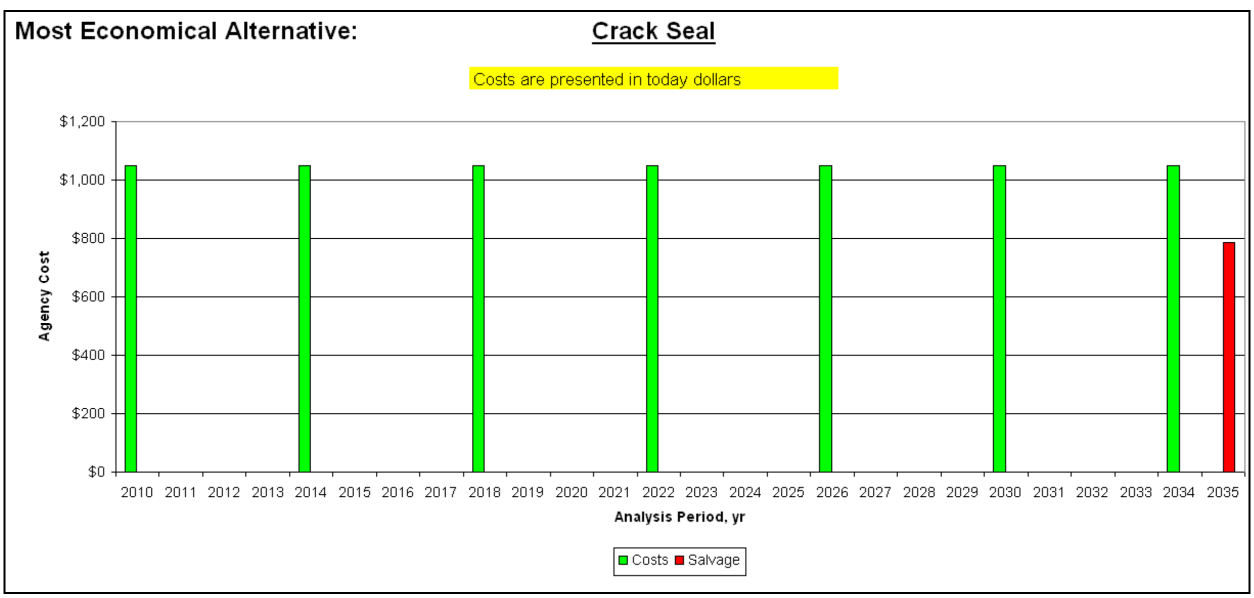


Figure C.9 – Section No. 6 LCCA Plot for the Most Economical Alternative.

Figure C.10 shows the graph that allows the user to visually compare the computed LCCA of any alternative with the most economical one shown on the previous graph, by selecting the comparative treatment method on a selection box. Same concept applies as in Figure C.10, the green values represent rehabilitation and maintenance costs while the red bar represents the salvage value of the construction at the end of the analysis period.

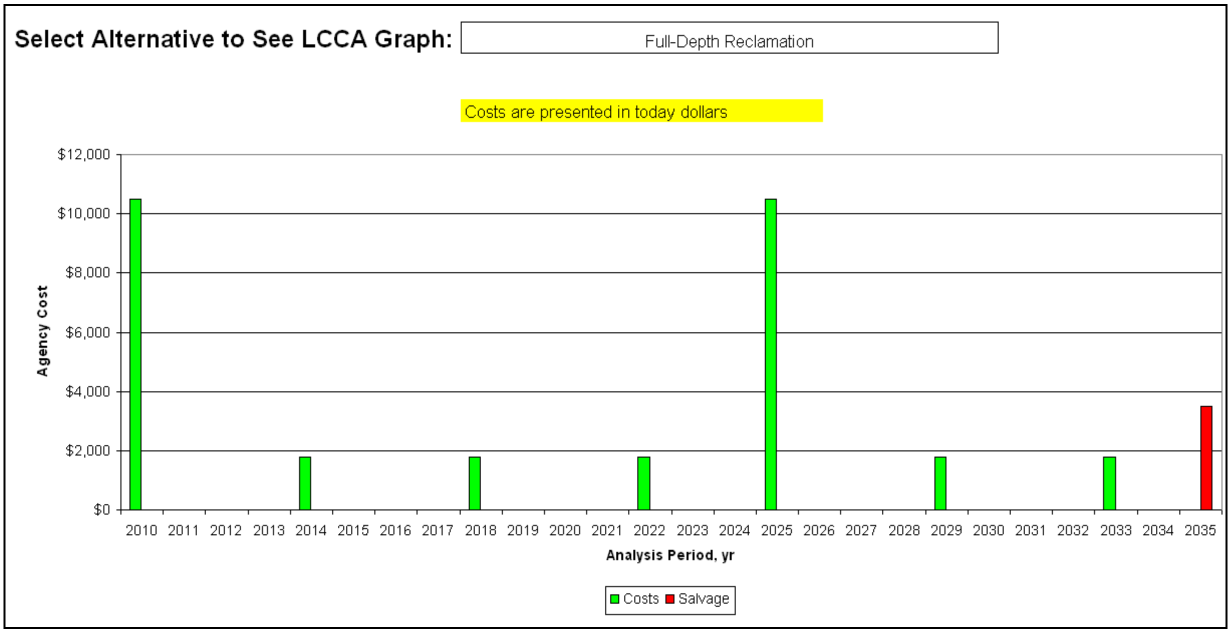


Figure C.10 – Section No. 6 LCCA Plot for a Selected Alternative.

C.7 COST AND LIFE EXPECTANCY SHEET

The table shown on Figure C.11 is found in the "Cost & Life" sheet of the program, and it provides default values, gathered in the literature, for construction and maintenance costs, and expected life for each of the remediation and maintenance alternatives. Values in this table may be adjusted by the user. Three empty spaces are left for the user to add the costs and life expectancies of additional alternatives.

	Alternatives	Unit Cost, sq. yd.		Expected Life, yrs
		Materials	Construction	
	Microsurfacing	$0.80	$0.40	4
	Fog Seal	$0.90	$0.40	4
	Crack Seal	$0.50	$0.20	4
	Sand Seal*	$0.70	$0.40	4
	Slurry Seal*	$0.70	$0.30	4
	Ultra-Thin Wearing Coarse	$0.90	$0.60	4
	Chip Seals	$0.90	$0.50	4
	Surface Treatment	$0.90	$0.40	4
	Hot In-Place Recycling	$1.00	$3.00	10
	Cold In-Place Recycling	$1.00	$2.50	10
	HMA & RAP Overlay	$2.00	$2.30	10
	Hot Mix Overlay	$2.00	$3.00	10
	HMA & Recycled Asphalt Shingles (RAS) Overlay	$2.00	$1.50	10
	PCC Overlay (Thick)	$3.00	$3.00	20
	Ultra-Thin Whitetopping*	$2.00	$2.50	15
	Full-Depth Reclamation	$3.00	$4.00	15
	Roller Compacted Concrete	$4.00	$4.00	25
	Stabilization	$1.50	$2.30	15
	Moisture Control	$1.50	$3.00	15
Additional				
	NONE	0	0	0

Figure C.11 – Cost and Life Expectancies for Each Alternative Table.

C.8 Remediation Methods Table Sheet

The table in Figure C.12 is found in the “Remediation Table” sheet of the program. Such table combines the predominant distresses at intersections with the recommended remediation alternatives and provides recommendations on how effective each remediation may be to solve

each of the distresses. The table contains a legend allowing to identify when an alternative is recommended, may be appropriate, not recommended, or simply doesn't apply to the defined problem. The recommendations are based on literature but may be adjusted to the user's own experience and knowledge, as long as the same labels are used. Also three empty spaces are left for the user to include and considerate additional alternatives in the analysis. The recommendation effectiveness of the additional alternatives to solve each distress should be added by the users.

Distress \ Treatment			Maintenance								Rehabilitation											Additional		
			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	Stabilization	Moisture Control			
Asphalt Layer	Surface Rutting	Low	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	X	X	X			
		Moderate	Y	N	M	M	M	N	M	M	M	M	M	M	M	Y	N	Y	X	X	X			
		High	M	N	N	N	N	N	N	N	M	M	M	N	M	Y	N	Y	X	X	X			
	Instability Rutting	Low	X	X	X	X	X	X	X	X	N	N	N	M	N	Y	N	Y	X	X	X			
		Moderate	X	X	X	X	X	X	X	X	N	N	N	M	N	Y	N	Y	X	X	X			
		High	X	X	X	X	X	X	X	X	N	N	N	M	N	Y	N	Y	X	X	X			
	Shoving	No Severity	X	X	X	X	X	X	X	X	N	N	N	M	N	N	N	Y	X	X	X			
	Fatigue Cracking	Low	Y	M	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	X	X	X			
		Moderate	M	N	M	M	N	M	Y	M	Y	Y	Y	Y	Y	N	N	Y	X	X	X			
		High	N	N	N	N	N	N	N	N	M	Y	Y	M	Y	N	N	M	X	X	X			
Base	Structural Rutting	Low	X	X	X	X	X	X	X	X	N	N	N	M	N	N	N	Y	N	Y	N			
		Moderate	X	X	X	X	X	X	X	X	N	M	M	M	M	N	N	Y	N	Y	N			
		High	X	X	X	X	X	X	X	X	N	N	N	N	N	N	N	Y	N	Y	N			
Sub-grade	Moisture Intrusion	No Severity	X	X	X	X	X	X	X	X	N	N	N	N	N	X	X	Y	X	Y	Y			
	Soil Structural Rutting	No Severity	X	X	X	X	X	X	X	X	N	N	N	N	N	X	X	Y	X	Y	Y			
High-Volume			X	X	X	X	X	X	X	X	N	N	N	N	N	Y	N	Y	Y	N	N			

Appropriate	Y
May Be Appropriate	M
Not Recommended	N
Not a Candidate	X

* No TxDOT Specification

Figure C.12 – Remediation Methods for Different Distresses Table.

C.9 PROGRAM DECISION TREE

Figure C.13 is found in the “Program Decision Tree” sheet of the program. The decision three is a tool that may help the user to follow the program’s steps. Even-though, the decision tree is based on the Remediation Methods Table, it doesn’t represent any thing else but a flow diagram.

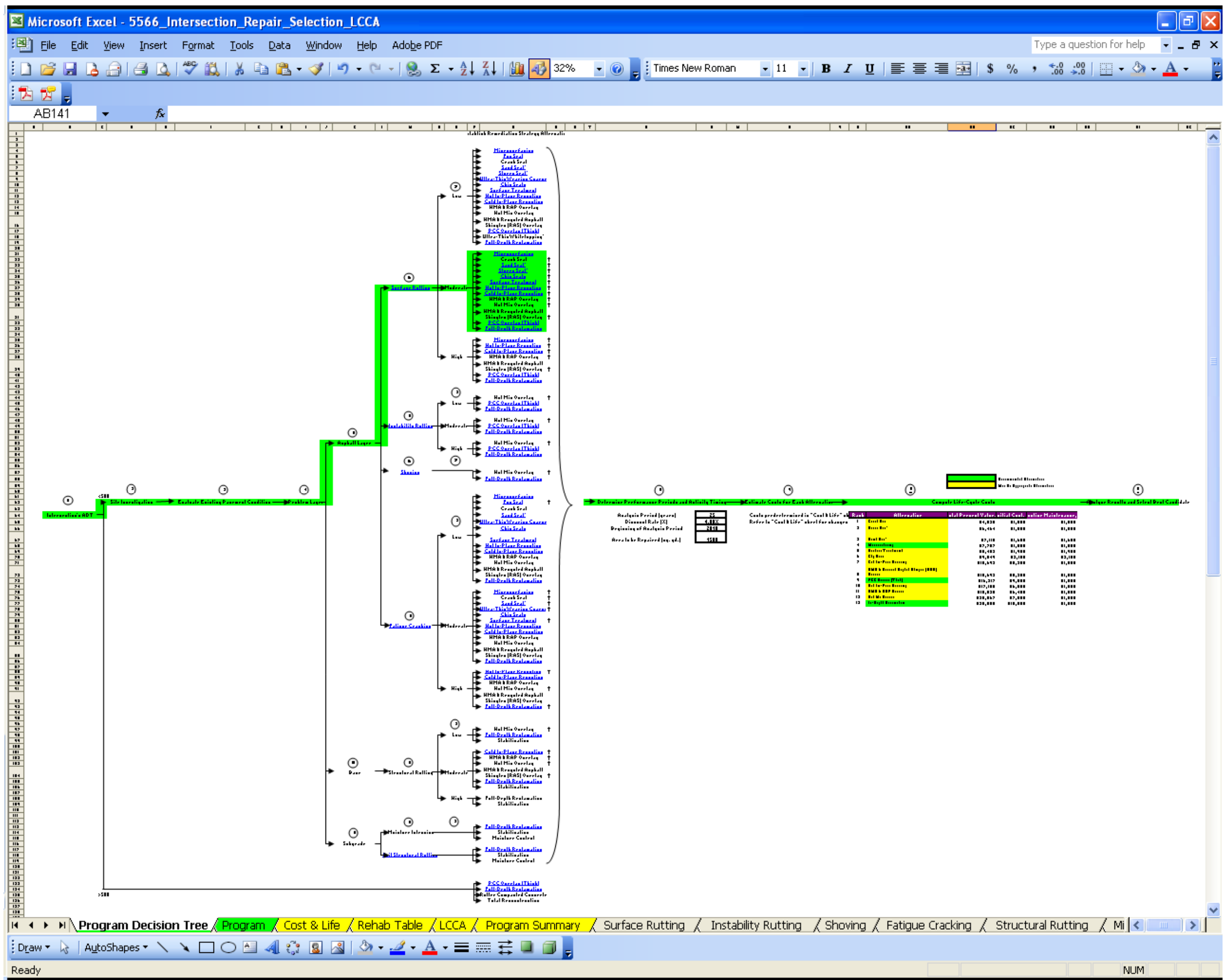


Figure C.13 – Decision Tree.

C.10 LCCA SHEET

The table shown on Figure C.14 is found in the “LCCA” sheet of the program. This table illustrates in detailed the calculated Initial Costs, Total Present and Salvage Values for the chosen alternatives, coupled with future maintenance costs over the life of the project. The Cost

column presents the costs in future value, while the Present Value column displays them in present worth. Here, the Beginning of Analysis Period is particularly used as the starting year of the analysis period. In order to differentiate costs from positive values (Salvage Value) colored numbers were used. In essence, black numbers represent cost, while red numbers stand for Salvage Value.

	B	D	E	F	G	H	I
4							
5		**Alternative 1**		**Alternative 2**		**Alternative 3**	
7		**Microsurfacing**		**Crack Seal**		**Sand Seal***	
13	**Year**	**Costs**	**Present Value**	**Costs**	**Present Value**	**Costs**	**Present Value**
14	2010	$1,800	$1,800	$1,050	$1,050	$1,650	$1,650
15	2011						
16	2012						
17	2013						
18	2014	$1,800	$1,539	$1,050	$898	$1,650	$1,410
19	2015						
20	2016						
21	2017						
22	2018	$1,800	$1,315	$1,050	$767	$1,650	$1,206
23	2019						
24	2020						
25	2021						
26	2022	$1,800	$1,124	$1,050	$656	$1,650	$1,031
27	2023						
28	2024						
29	2025						
30	2026	$1,800	$961	$1,050	$561	$1,650	$881
31	2027						
32	2028						
33	2029						
34	2030	$1,800	$821	$1,050	$479	$1,650	$753
35	2031						
36	2032						
37	2033						
38	2034	$1,800	$702	$1,050	$410	$1,650	$644
39	2035	$1,350	$506	$788	$295	$1,238	$464
75	**Total PV**	**$11,250**	**$7,757**	**$6,563**	**$4,525**	**$10,313**	**$7,110**
76							

Figure C.14 – LCCA Table.

C.11 ESAL TABLES SHEET

The tables shown on Figure C.15 are found in the “ESAL Tables” sheet of the program. The Combination of Trucks as Percentage of AADT, Truck Factor and Lane Distribution Factor Tables work together in Section No. 3 in order to find the value of Daily ESALs at the intersection. More importantly, the Daily ESALs value is needed to classify the intersection into low or high volume road, and then obtain the appropriate alternatives that will achieve the

structural and performance objectives of the project. Section No. 3 has default values of .52 and 1.00 for the Truck Factor and Lane Distribution Factor respectively. In addition, Section No. 3 includes hyperlink such tables for the user to modify the defaulted values.

DISTRIBUTION OF TRUCKS ON DIFFERENT CLASSES OF HIGHWAYS IN THE UNITED STATES

	Percent Trucks											
	Rural Systems						Urban Systems					
			Collectors									
Truck Class	Interstate	Other Principal	Minor Arterial	Major	Minor	Range	Interstate	Other Freeways	Other Principal	Minor Arterial	Collectors	Range
Single-unit Trucks												
2-axle, 4 tire	43	60	71	73	80	43-80	52	66	67	84	86	52-86
2-axle, 6 tire	8	10	11	10	10	8-11	12	12	15	9	11	9-15
3-axle or more	2	3	4	4	2	2-4	2	4	3	2	<1	<1-4
All single units	53	73	86	87	92	53-92	66	82	85	95	97	66-97
Multiple-unit Trucks												
4-axle or less	5	3	3	2	2	2-5	5	5	3	2	1	1-5
5-axle*	41	23	11	10	6	6-41	28	13	12	3	2	2-28
6-axle or more*	1	1	<1	1	<1	<1-1	1	<1	<1	<1	<1	<1-1
All multiple units	47	27	14	13	8	8-47	34	18	15	5	3	3-34
All Trucks	100	100	100	100	100		100	100	100	100	100	

+ Compiled from data supplied by the Highway Statistics Division, U.S. Federal Highway Administration.
* Including full-trailer combinations in some states
Source. After Al (1991)

Figure C.15a – Combination of Trucks as Percentage of AADT.

DISTRIBUTION OF TRUCK FACTORS FOR DIFFERENT CLASSES OF HIGHWAYS AND VEHICLES IN THE UNITED STATES

	Truck Factors											
	Rural Systems						Urban Systems					
			Collectors									
Truck Class	Interstate	Other Principal	Minor Arterial	Major	Minor	Range	Interstate	Other Freeways	Other Principal	Minor Arterial	Collectors	Range
Single-unit Trucks												
2-axle, 4 tire	0.003	0.003	0.003	0.017	0.003	.003-.017	0.002	0.015	0.002	0.006	-	0.006-0.015
2-axle, 6 tire	0.21	0.25	0.28	0.41	0.19	0.19-0.41	0.17	0.13	0.24	0.23	0.13	0.13-0.24
3-axle or more	0.61	0.86	1.06	1.26	0.45	0.45-1.26	0.61	0.74	1.02	0.76	0.72	0.61-1.02
All single units	0.06	0.08	0.08	0.12	0.03	0.03-0.12	0.05	0.06	0.09	0.04	0.16	0.04-0.16
Tractor semitrailers		0.92	0.62	0.37	0.91	0.37-0.91	0.98	0.48	0.71	0.46	0.4	0.40-0.98
4-axle or less	0.62	1.25	1.05	1.67	1.11	1.05-1.67	1.07	1.17	0.97	0.77	0.63	0.63-1.17
5-axle*	1.09	1.54	1.04	2.21	1.35	1.04-2.21	1.05	1.19	0.9	0.64	-	0.64-1.19
6-axle or more*	1.23	1.21	0.97	1.52	1.08	0.97-1.52	1.05	0.96	0.91	0.67	0.53	0.53-1.05
All multiple units	1.04	0.38	0.21	0.3	0.12	0.12-0.52	0.39	0.23	0.21	0.07	0.24	0.07-0.39
All Trucks	0.52											

+ Compiled from data supplied by the Highway Statistics Division, U.S. Federal Highway Administration.
* Including full-trailer combinations in some states
Source. After Al (1991)

Figure C.15b – Truck Factor.

LANE DISTRIBUTION FACTOR

No. of Lanes in Each Direction	Percentage of 18-kip ESAL in Design Lane
1	100
2	80-100
3	60-80
4	50-75

Source. After AASHTO (1986)

Figure C.15c – Lane Distribution Factor.

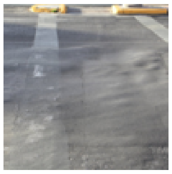
C.12 COMMON DISTRESSES AND REMEDIATION STRATEGIES SHEETS

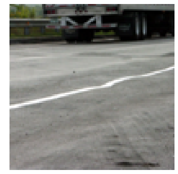
The table shown on Figure E.16 is found on one of the several common distresses sheets of the program. As stated on Section No. 4, the Intersection Repair Method Selection Spreadsheet establishes its problem identification based on visual aids. As consequence, sections where the common distresses are summarized were added. The common distresses synopsis includes a brief description for each distress, the distresses causes, preventive and overall solutions, and finally the rehabilitation alternatives. To end with, the common distresses sheets will also have pictures showing the severities that the distresses might experience.

Shoving/Corrugation

Description:

Shoving is a form of plastic movement typified by ripples (corrugation) or an abrupt wave (shoving) across the pavement surface. The distortion is perpendicular to the traffic direction. Usually occurs at points where traffic starts and stops (corrugation) or areas where HMA abuts a rigid object (shoving).





Causes:

- Unstable Mix
- Braking, stopping, accelerating traffic
- Slippage between layers
- Poor interlayer bond
- Poor construction
- Heavy trucks
- Moisture damage
- Shrinkage of stabilized layers (too much stabilizer)
- Asphalt cement properties (burnt binder)

Solutions - Cures:

- Remove and Replace
- Remove and Overlay

Solutions - Prevention:

- NovaChip® surfacing
- The use of quality design, quality aggregate, quality liquid asphalt, and quality construction
- A good tack between layers
- Elastomeric polymer modified binders have been found to be especially Fatigue cracking is one of the

Rehabilitation Alternatives:

- Seal Coat
- Rubberized seal coat and overlay

High severity cracking

- Crack seal
- Crack relief layer and structural overlay

High severity cracking with loss in ride

- Crack relief layer and structural overlay
- Flexible base overlay and resurfacing
- Surface removal and full depth base reclamation

Figure C.16 – Common Distress Sheet for Shoving/Corrugation.

The table shown on Figure C.16 is found on one of the several common remediation strategies sheets of the program. Similarly, sections where the remediation strategies are summarized were also added. The remediation strategies synopsis includes a brief description of

each product, the typical traffic range, life expectancies, unit prices, appearance, advantages and limitations. Finally, the remediation strategies sheets will also have pictures of the remediations.

<u>Microsurfacing</u>

Product Description:

Microsurfacing, an enhanced slurry seal, is composed of a mixture of polymer-modified emulsified asphalt, dense-graded crushed fine aggregate, mineral filler or other additives, and water. Microsurfacingis used as a

Traffic Range:

No limitations. Typically used for AADT > 400.

Life Expectancy:

5 to 8 years (average 7 years).

Unit Price:

Material & Installation: \$3.10 to \$3.90/m2(\$2.60 to \$3.30/yd2).

Appearance:

Microsurfacingis usually black with a fine surface texture. Microsurfacing color can be modified by the use of pigments in the microsurfacing mix.

Advantages:

High quality surface treatment; Excellent skid resistance; Can rehabilitate instability rutting.

Limitation:

Higher initial cost than some other surface treatments; Specialty contractors required.

Figure C.17 – Common Remediation Strategies for Microsurfacing.

APPENDIX D: REMEDIATION STRATEGIES

Remediation strategies divide into two categories: (1) Preventive Maintenance Treatments which are low-cost treatments that retard deterioration of the pavement, maintain or improve the functional condition of the roadway, and extend the pavement's service life when applied on suitable candidates, and (2) Rehabilitations which repair the condition of the existing pavement structure.

MICROSURFACING

The main use of micro-surfacing materials is for pavement preservation as a part of a program of periodic surfacing before distresses appear. Micro-surfacing is a mixture of asphalt emulsion, graded aggregates, mineral filler, water and other additives. The mixture is made and placed on a continuous basis using a travel paver (Slurry Surfacing Machine). The travel paver meters the mix components in a predetermined order into a pug mill. The typical mixing order is aggregate followed by cement, water, the additive and the emulsion. Distress modes that can be addressed using micro-surfacing include:

- Raveling: Loose surfaces or surfaces losing aggregate may be resurfaced using slurry seals or micro-surfacing.
- Oxidized pavement with hairline cracks: These surfaces may be resurfaced using slurry seals or micro-surfacing.
- Rutted pavements: Deformation resulting from consolidation of the surfacing only. Rutting due to base failure of significant plastic deformation of the HMA cannot be treated except as a temporary measure.
- Rough pavements with short wavelength: These irregularities may be treated with micro-surfacing, provided the frequency of the irregularities is shorter than the spreader box width.

Distress modes that cannot be addressed using micro-surfacing include:

- Cracking (including reflection cracking)
- Base Failures of any kind

- HMA Layers that exhibit plastic shear deformation

Micro-surfacing will not alleviate the cause of these distresses. As a result, the distresses will continue to form despite the application of a slurry surfacing.

FOG SEAL

According to the Asphalt Emulsion Manufacturers Association (AEMA) a fog seal is a light spray application of dilute asphalt emulsion used primarily to seal an existing asphalt surface to reduce raveling and enrich dry and weathered surfaces. A fog seal is made to coat, protect, and rejuvenate the existing asphalt binder. The addition of asphalt will also improve the waterproofing of the surface and reduce its aging susceptibility by lowering permeability to water and air. To achieve this, the fog seal material (emulsion) must fill the voids in the surface of the pavement. Therefore, during its application it must have sufficiently low viscosity so as to not break before it penetrates the surface voids of the pavement. This is accomplished by using a slow setting emulsion that is diluted with water. Emulsions that are not adequately diluted with water may not properly penetrate the surface voids resulting in excess asphalt on the surface of the pavement after the emulsion breaks, which can result in a slippery surface.

CRACK SEAL

Crack sealing and filling prevent the intrusion of water and incompressible materials into cracks. The methods vary in the amount of crack preparation required and the types of sealant materials that are used. Crack sealing is the placement of materials into working cracks. Crack sealing requires thorough crack preparation and often requires the use of specialized high quality materials placed either into or over working cracks to prevent the intrusion of water and incompressible materials. Crack sealing is generally considered to be a longer-term treatment than crack filling. The pavement structure should be sound and cracks are only treated when greater than 1/4in. or up to 1in. (Caltrans, 2003)

SAND SEAL

A sand seal is a thin asphalt surface treatment constructed by spraying a bituminous binding agent and immediately spreading and rolling a thin fine aggregate (i.e. sand or screenings) cover. A sand seal is basically the same as a chip seal except that finer aggregate is used in the cover. Application of this sealer fills cracks and seals the surface against damage from water, sunlight, gas and oil. Aggregates help make the sealed surface less slippery when wet.

This sand seal is intended to be used on pavements that have lost some of their matrix, and it is desirable for tightening the pavement texture and reducing raveling. Blend of heavy mineral fillers and fine aggregates works well on large areas of fatigue cracking. Typical AADT<400 when placed on aggregate base. Typical AADT<2,000 when placed on existing HACP.

SLURRY SEAL

Slurry seal is a mixture of emulsified asphalt oil, rock, water, and additives such as aluminum sulfate, Portland cement, lime, latex or carbon black. Which additives are used depends on many factors including location, condition of surface, and the type of surface. All these factors should be considered when the laboratory designs a mix. Slurry Seals are treatments that provide pavement sealing and pavement texture but are not appropriate to resolve structural pavement deficiencies. These systems are well suited as a preventive maintenance treatment to extend the life of structurally sound low traffic volume pavements.

CHIP SEALS

Chip sealing is the application of a bituminous binder immediately followed by the application of an aggregate. The aggregate is then rolled to embed it into the binder. Multiple layers may be placed and various binder and aggregate types can be used to address specific distress modes or traffic situations. Polymer-Modified Emulsion (PME) chip seals are normally not suitable for intersections or high stress areas. Conventional chip seals are used on

structurally sound pavements with minimal cracking. Deformation, rutting and shoving cannot be addressed with chip seals of any kind.

HOT IN-PLACE RECYCLING (HIPR)

This rehabilitation technique is meant to address asphalt concrete surface distress and texture issues only, therefore the underlying base layers must offer adequate support.

The HIPR process involves recycling the existing asphalt surface layer by heating, scarifying, and adding a recycling agent. There are three basic HIPR processes:

1. Heater-scarification - heating, scarifying, rejuvenating, leveling, reprofiling, and compacting.
2. Repaving - heating, scarifying, rejuvenating, leveling, laying a new hot mix layer, reprofiling, and compacting.
3. Remixing - heating, scarifying, rejuvenating, mixing (adding a new hot mix), leveling, reprofiling, and compacting.

Pavements with delaminations, especially saturated delaminations, in the top 2in. should not be considered for HIPR projects. Also, the state of practice does not recommend pavements that have been rutted, heavily patched, or chip-sealed as good candidate projects. Typically, hot in-place recycling operations are conducted when the ambient air temperature is 50ºF and rising, but 2004 specifications cite a minimum surface temperature for hot mix asphalt (HMA) placement of 60ºF. An additional overlay may be placed over the recycled surface if additional structural strength is needed as in the case of the repaving process. An equivalent alternative strategy is to mill 1in. of the existing top layer and place back 2in. Up to 30% RAP may be allowed in the new 2in. overlay. (TxDOT, 2006)

COLD IN-PLACE RECYCLING (CIPR)

As with the hot in-place process, this rehabilitation technique is meant to address distress within the bituminous portion of the pavement structure, but can reach as deep as 4 to 6in. Therefore, the base must also be sound, with repairs made to locations that have failed or show

potential for failure. The process also involves a specialized train with a cold milling machine, crushing/screen unit, and mixing unit that is capable of reclaiming the old asphalt, crushing (screening and sizing) the RAP, and mixing the RAP with virgin aggregate (if necessary) and emulsion. Coring of the existing ACP surface is necessary to determine the material properties of the existing asphalt pavement to properly design proportions of virgin aggregate, emulsion and rejuvenator, if necessary. Cores are also inspected for the presence of variations in the pavement layers, delaminations and whether voids are saturated. The industry does not recommend pavements that have been rutted, heavily patched, or chip-sealed as good candidate projects. Generally, a seal coat or additional overlay will be required after adequate curing since the cold re-processed mix has higher void ratios and is more difficult to compact than hot mix. (TxDOT, 2006)

HMA & Recycled Asphalt Shingles (RAS) Overlay

Special specifications for Hot Mix Asphalt concrete pavement containing reclaimed roofing shingles are in TxDOT Item 3028

PCC Overlay (Thick)

Applying a concrete overlay on a HMA surfaced pavement may be a viable rehabilitation strategy under certain circumstances. Where existing distress in an HMA-surfaced structure is confined to the HMA itself (mix rutting, shoving, washboarding, cracking), but otherwise the existing substructure is sound, a concrete overlay can offer a durable replacement surface. These circumstances may present themselves at intersections or along open sections of highway. Design can be for jointed or continuously reinforced concrete pavement (CRCP) overlays. (TxDOT, 2006)

Ultra-thin Whitetopping

Ultrathin whitetopping use slabs from 2.0 to 4.0in. thick that are placed on an HMA surface that has been milled or otherwise prepared to enhance the bond. Any concrete overlay thinner than 4.0” is not currently allowed under TxDOT guidelines. This may restrict the use of

concrete overlays at certain curb and gutter intersections where vertical profile may not allow direct placement on top of the existing HMA structure, and milling to the appropriate depth may leave insufficient support. (TxDOT, 2006)

FULL DEPTH RECLAMATION

This rehabilitation procedure entails pulverizing the old pavement structure, blending in a stabilizing agent, compacting, adding additional material, and resurfacing. This procedure is meant to address deep structural problems ranging to depths as great as 12in. in the existing structure. This is the practical limit of recycler cut-in and subsequent compaction of the recycled layer. Deeper problems must be addressed by temporary storage such as windrowing removed material in the right of way (ROW) or otherwise moving existing material off site. Efficiency is improved by using a specialized train to reprocess the existing structure. New base and surfacing is then applied to provide appropriate additional structure, ride quality, skid, weatherproofing, etc. (TxDOT, 2006)

APPENDIX E: CORE SUMMARIES FROM INTERSECTION OF SH49 AND SH155

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

Core	# 1 Center
Thickness, in	.5
Location	SH 155 South bound 500ft 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

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

Core	# 1 OWP
Thickness, in	2.5
Location	SH 155 South bound 500ft north
Modulus	256 ksi
Asphalt Content	6.99 %

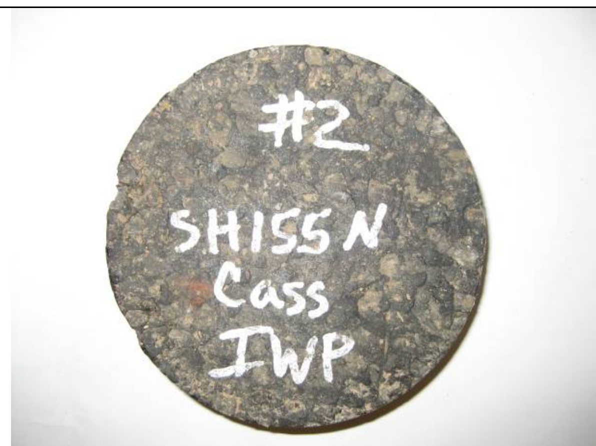
Notes:

- 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

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



Notes:

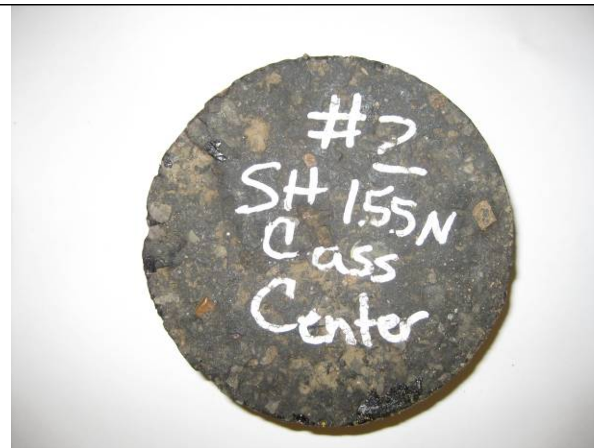
- Low to severe fatigue cracking , rutting, loss of aggregate, bleeding, pushing, and block cracking
- FWD data collected at this location

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

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

Core	# 2 Center
Thickness, in	2.5
Location	SH 155 South bound 100ft north
Modulus	547 ksi
Asphalt Content	8.46 %



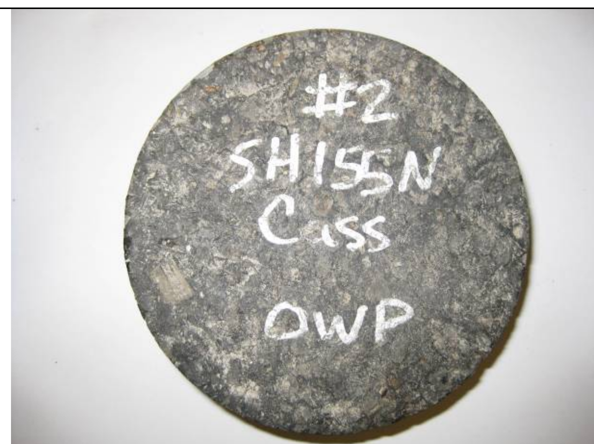
Notes:

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

Core	# 2 OWP
Thickness, in	2.4
Location	SH 155 South bound 100ft 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

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

Core	# 3 IWP
Thickness, in	4.2
Location	SH 49 Eastbound 500ft 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

Core	# 3 Center
Thickness, in	4.2
Location	SH 49 Eastbound 500ft West
Modulus	562 ksi
Asphalt Content	4.93 %

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

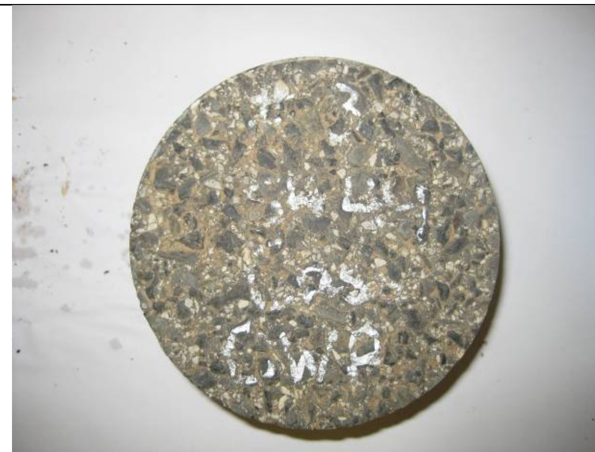
Size	(g)
1/2"	35.8
3/8"	152.7
#4	436.2
#40	594.1
#100	141
#200	26
Pan(-200)	31.8

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

Core	# 3 OWP
Thickness, in	4
Location	SH 49 Eastbound 500ft West
Modulus	590 ksi
Asphalt Content	5.4 %

Notes:

Cement detected on the base with Phenolphthalein

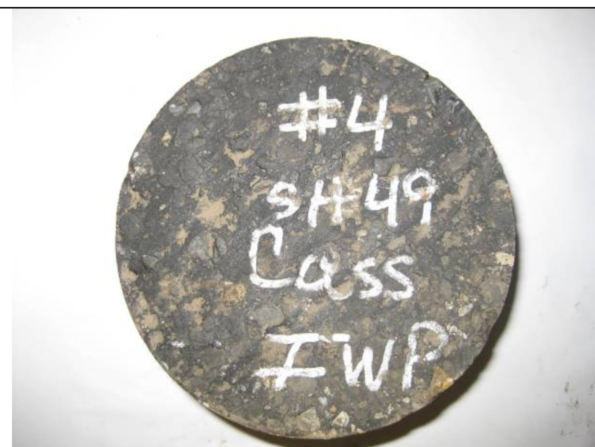


Gradation

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

Core	# 4 IWP
Thickness, in	3.2
Location	SH 49 Eastbound 75ft 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

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

Core	# 4 Center
Thickness, in	3.1
Location	SH 49 Eastbound 75ft 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

Core	# 4 OWP
Thickness, in	3.1
Location	SH 49 Eastbound 75ft 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

APPENDIX F: CHECK LISTS FOR FUTURE SITE VISITS

Table F.1a: A Checklist of Information that Should be Collected at Intersections (Part1).

<u>Pavement Design of the Intersection</u>	
Asphalt Layer	
	Thickness
	Modulus
	Type of Mix
	Mix Design
Base and/or Subbase	
	Thickness
	Modulus
	Stabilized
Subgrade	
	Modulus
	Stabilized
<u>Traffic Information from Transportation Planning and Programming Division</u>	
	Traffic predictions for year of construction for each road
	Traffic predictions for end of analysis period for each road
	Truck factor for each road
	Lane distribution Factor for Each Road
	Truck percentage for each road
<u>Geometry of Intersection</u>	
	Number of lanes
	Direction of each lane
	Type of signalization
	Number of Turning lanes

Table F.1b: A Checklist of Information that Should be Collected at Intersections (Part2).

<u>Visual Survey</u>	
	Identify every distress and severity
	Record total extension (area or length)of every distress
	Photos of every distress (include a ruler in the close-up images)
	Surface and subsurface drainage conditions
	Rut profile depth measurements (use 6 ft straight edge)
	Rut widths
	Identify possible locations for testing (FWD, GPR, Coring, Trenching, and DCP)
<u>Field Testing</u>	
Falling Weight Deflectometer (FWD)	
	Test a minimum of 30 points (The most points the better)
	Decrease the distance between points as approaching the intersection
	Clearly specify locations

	Make as many comments on the conditions of the locations as possible
Dynamic Cone Penetrometer (DCP)	
	Perform at least one test per core hole
	Clearly specify locations
	Repeat test in case tip runs into a rock
Ground Penetrating Radar	
	Clearly specify locations
Trenching	
	The size of each trench is 3 ft. X 6 ft.
	Smoothen one of the walls (perpendicular to traffic)
	Photos (Use chalk or string lines between layers to differentiate)
Cores	
	Label
	Thickness
	Photo
	Clearly specify locations
Base and Subgrade Sampling	
	Enough material for laboratory testing

Table F.1c: A Checklist of Information that Should be Collected at Intersections (Part3).

Laboratory Testing	
Asphalt Cores	
	Trim rough surface or base
	Measure height
	Weight
	V-meter
	Gradation
	Bulk Specific Gravity (Gmb)
	Extraction of binder
	Viscosity of binder
	Hamburg Wheel Tracking Device on cores
	IDT strength of cores
	Complex Modulus and Permanent Deformation on lab specimens prepared at field air voids
	NCAT Ignition
Base and Subgrade Materials	
	Gradation and Atterberg Limits
	Moisture Density Curve
	Texas Triaxial Tests
	Resilient Modulus/Permanent Deformation Tests at Optimum Moisture Content
	Resilient Modulus/Permanent Deformation Tests at In-place Moisture Content
	Moisture Susceptibility

In addition several considerations for the data collection process are discussed below.

CURRENT PAVEMENT DESIGN

The first step in every site investigation should be the collection of all the existing data prior to any visit or analysis. The general pavement information can be obtained from the last pavement design blueprints. From the cross sectional design of the structure is important to gather each layer characteristics, for instance thicknesses, type of asphalt mix, type of base, find if base and/or subgrade are stabilized and which stabilization agents (additives) were used for the construction. The geometry of the intersection is also essential for the analysis, the number of lanes in each road and direction as well as the type of signalization needs to be documented.

TRAFFIC INFORMATION

The traffic projections should be requested to the Transportation Planning and Programming Division. The data obtained should be enough not only to quantify the number of vehicles (ADT) but the magnitude (ESAL) of traffic loading, which will determine the stresses induced to the pavement and will allow to classify the road. The AADT for the year of construction, projected AADT for the end of analysis period, truck factor, lane distribution factor and truck percentages are needed to calculate the ESALs. If the projected ESALs fro the length of the analysis period are provided by the TPP the previous information is not needed.

VISUAL SURVEY

Visual surveys serve as a qualitative indicator of the overall pavement condition, for both functional and structural properties. Specialized equipments and procedures are then used to quantify both functional and structural aspects of the pavement structure. That is the reason why the identification of distressed areas to select locations for further inspection is a useful aspect of condition surveys. The type, extent (area or length), and severity of every distress should be recorded properly and supported with a photograph, and the predominant distress should be identified. Rut depths and widths should also be recorded to provide better clues in the identification of the problematic layer of the structure.

NON DESTRUCTIVE TESTING

The most common NDT tools used by TXDOT are FWD, GPR, and DCP. Data collected from NDT in the filed is generally objective, but subjectivity often appears in the analysis and interpretation. The most information possible should be collected in the field for the analyst to carry out a better evaluation and it is of great importance to encourage the operator to write as many comments as possible on the conditions of the pavement and progress of the test. In the case of GPR and FWD is extremely important to locate the starting and finishing points of the analysis, while for the DCP the locations at which the tests were performed. Being the intersections the main focus of the evaluation is important to increment the number of FWD collection points as approaching the intersection by reducing the distance between points to 25 ft. Data collected from NDT is a very useful evaluation tool for the structural support of pavement, and can be used to evaluate the need for further destructive testing.

DESTRUCTIVE TESTING

Trenching and coring are used to determine the source of the problematic layer when FWD, GPR, or DCP can not differentiate from which layer the deformation comes from. Destructive testing provides more detailed data about the mechanical, physical, and chemical properties of the pavement, information not possible to obtain through NDT. TXDOT has specific procedures on the Pavement Design Guide for trenching and coring and they should be followed thoroughly. It is important to take photos of both the trench and cores for documentation and solve any future doubts. Location of each core hole has to be precisely recorded and every core has to be labeled and measured at the time of extraction.

LABORATORY TESTING

From the cores, base and subgrade materials brought to the laboratory is necessary to perform the following procedures following TXDOT specifications. A sample summary of the cores created by CTIS personnel is in Appendix E. The following tests on the asphalt cores are considered necessary for the analysis.

- Core dimensions
- V-meter
- Gradation
- Bulk Specific Gravity (Gmb)
- Extraction of binder
- Viscosity of binder
- Hamburg Wheel Tracking Device on cores
- IDT strength of cores
- NCAT Ignition
- Complex Modulus and Permanent Deformation on lab specimens at field air voids

For base and subgrade materials the following procedures provide the information necessary for analysis.

- Gradation and Atterberg Limits
- Moisture Density Curve
- Texas Triaxial Tests
- Resilient Modulus/Permanent Deformation Tests at Optimum Moisture Content
- Resilient Modulus/Permanent Deformation Tests at In-place Moisture Content
- Moisture Susceptibility

VITA

Carlos J. Solis was born on August 9, 1983 in Camargo, Mexico. The third son of Carlos Solis and Victoria Eugenia Lopez, he graduated from Tecnologico de Monterrey High School, Chihuahua, Mexico in the spring of 2001 and entered the University of Texas at el Paso (UTEP) in the fall of the same year. He received his bachelor's degree in Civil Engineering in 2007. In the spring of 2008 he entered the Civil Engineering graduate program at UTEP.

Permanent address: Calzada Revolucion 451

Cuauhtemoc, Chihuahua, Mexico

This thesis/dissertation was typed by Carlos Solis