Maintenance and Rehabilitation Strategies for Repair of Road Damage Associated with Energy Development and Production

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INTRODUCTION

From 12,000 to 24,000 oil and gas wells were permitted each year in Texas during the last decade (1). The development of the state's oil and gas reserves has provided a significant economic impact to the state (2, 3) and nation and could continue decades into the future.

The rapid development of the state's oil and gas resources has required large volumes of relatively heavily loaded trucks per well developed. This truck traffic has significantly impacted the Texas Department of Transportation (TxDOT) Farm to Market (FM) road network as well as its trunk State Highway (SH) and United States (US) route designated highways.

One of the major issues facing TxDOT maintenance forces is the repair of this impacted road network. The maintenance and repair of this roadway system has required an ever increasing amount of TxDOT's financial resources and available workforce. Routine maintenance costs on these FM roadways have increased from typical values of from $500 to $1,500 per centerline mile to $35,000 to $45,000 per centerline mile due to the development of these wells (4).

Repair costs for state and local government roadways have been estimated at 2 billion dollars per year (5). If financial resources are not available to repair the roadways the cost to the energy development industry due to rough roads (equipment damage and lower operating speeds) could be in the 1.5 to 3.5 billion dollar range annually (6).

It is estimated that TxDOT will expend approximately $500 million annually for maintenance and rehabilitation of roadways impacted by oil and gas development each year for the fiscal years 2015 to 2017. Local governmental agencies are expected to expend over 200 million during this same fiscal year period.

BACKGROUND

In anticipation of these continuing large expenditures, TxDOT has formed a special design and operating group within the Maintenance Division to assist Districts, manage the program and provide information to the administration. The TxDOT Maintenance Division initiated an Interagency Agreement Contract (IAC) with the Texas A&M Transportation Institute as part of this effort. One of the tasks of this agreement is the joint preparation of strategies/guidelines to assist Districts in their decision making relative to selecting maintenance and repair strategies for this impacted roadway network.

This document is intended to assist the Districts with making investment decisions for the maintenance and repair of roadways impacted by oil/gas development and production. More detailed documents used to develop these guidelines/strategies are identified below.

1. Current TxDOT Practices for Repair of Road Damage Associated with Energy Development and Production (7)
2. Truck Traffic and Truck Loads Associated with Unconventional Oil and Gas Development in Texas (8)
3. Project Level Pavement Evaluation Guidelines (9)

4. Pavement Structural Design Considerations for Establishing Paved Shoulder Widths Associated with Repair of Road Damage by Energy Development and Production (10)
5. Structural Design Considerations Associated with Repair of Road Damage by Energy Development and Production (11)
6. Simplified Life Cycle Cost Estimating (12)

These documents capture recommended practices as well as providing additional information on traffic, pavement structural design considerations and life cycle costing.

OVERVIEW OF GUIDE

Figure 1 provides a flow diagram indicating the key steps used by Districts to select a maintenance/rehabilitation method for repairing the pavement and shoulders on a specific roadway impacted by oil/gas development and production. The key steps in this process include the following:

1. Define geometrics of project-Step 1
2. Assess condition of the existing project-Step 2
3. Estimate traffic volumes and weights expected on the facility over its design life-Step 3
4. Determine the required pavement thickness (main lanes and shoulders)-Step 4
5. Consider project constraints including financial resources and workforce-Step 5
6. Choose maintenance or rehabilitation strategies including:
   a. Routine maintenance- Step 6
   b. Preventive maintenance- Step 7
   c. Rehabilitation-Step 8
7. Economic Analysis-Step 9
8. Selection of Alternative-Step 10

Additional details associated with these individual steps are provided below. References noted within the steps are provided for the background associated with the development of the guidelines. The flow chart in Figure 1 is intended to provide a checklist of actions to be taken when assessing the maintenance and rehabilitation needs of a particular roadway within the constraints imposed by budgets and labor availability.

PROJECT DEVELOPMENT STEPS

GEOMETRICS-STEP 1

Project geometrics include:

1. Right of Way widths
2. Lane widths
3. Shoulder widths
4. Drainage including widths of drainage structures (culverts as well as bridges) and the presence of roadside drainage features
5. Horizontal and vertical curves
6. Intersections
7. Driveways
8. Curbs/gutters and
9. Adjacent business access.

These geometric features will impact the maintenance/rehabilitation alternative selection process.

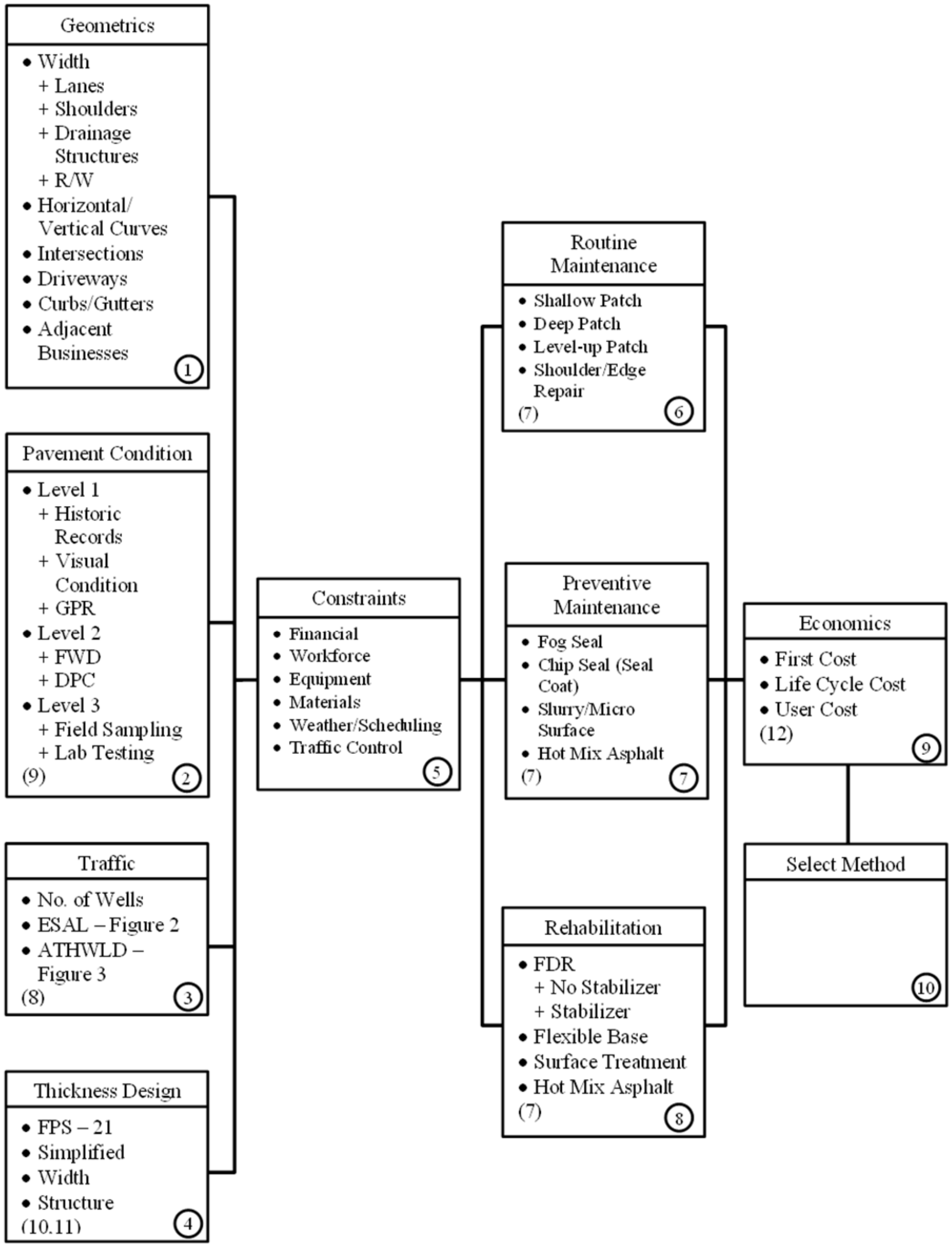

Figure 1. Key Steps for Selecting Maintenance and Rehabilitation Strategies.

The Farm to Market road system was originally developed to provide access for the state farmers and ranchers to their markets. These roadways were designed for relatively low traffic volumes. Many of these roadways are 18 to 22 ft. in width without paved or improved shoulder materials. The widening of these roadways to handle the increased volumes and weights of oil and gas development and production generated traffic is a very high priority item for TxDOT. The widths of the right-of-way and widths of drainage structures are important considerations when determining maintenance and rehabilitation alternatives for selected projects. Widening roadways with narrow drainage structures without widening these structures presents a safety problem although the widening of drainage structures is costly.

Existing lane widths and shoulder widths and their thicknesses are inputs to structural design and widening considerations. The amount of materials for cold in-place recycling (full depth recycling (FDR)) operations commonly utilized for widening these roadways is directly dependent on the width and thickness of the existing travel lanes and shoulders.

Adequacy of horizontal and vertical curves from a safety point of view (including sight distance) should be considered as part of the process of selecting a suitable maintenance or rehabilitation alternative. The need for correcting horizontal and vertical curves is largely a safety issue and can be costly.

The adequacy of existing intersections to carry additional traffic should be considered as part of the decision making process. Right turn lanes, protected left turn lanes and other safety issues should be addressed as funding allows.

Driveways are needed to provide access for oil and gas development. These driveways should be designed to allow for the wide turning radii associated with large haul units. Widening may be necessary on both sides of the roadways near the driveway to the oil and gas development area.

Driveways and curb and gutter features are needed to provide safe and efficient access to roadway, adjacent businesses. As oil and gas development and production activities increase in a given geographic area, oil/gas service industries install fixed facilities that generate considerable heavy truck traffic.

PAVEMENT CONDITION-STEP 2

The condition of the existing pavement and shoulder needs to be defined. The extent of the effort expended to determine the pavement condition is dependent upon the available budget and workforce needs of the project. If sufficient funds are available for rehabilitation, then a higher level of effort should be used to define the pavement and shoulder conditions. Reference 9 provides details relative to determining pavement condition.

Three levels that can be used to determine pavement condition are defined below. The length of the project and the money available to the project for maintenance or rehabilitation should be used to determine the level of effort and cost expended in gathering pavement condition information. Note that each successive level includes the level or levels above it, i.e., “Level Two” efforts include all activities associated with Level One and Two activities and “Level Three” activities include all activities associated with Levels One, Two and Three activities. Reference 10 provides more details for the activities briefly described below.

Level One

This approach is appropriate when time constraints and pavement conditions indicate that structural problems are most likely not present and that rehabilitation may not be warranted. The methods employed (reviewing historical records, conducting visual survey, and using a GPR survey) may all be done within a short period of time and provide sufficient information to develop a maintenance plan. However, if records indicate a rapid increase in truck traffic or the visual survey shows indications of deep rutting or structural cracking or the GPR survey indicates excessive moisture in the structure, a Level Two evaluation may be in order.

Historical Records

As-built plans and maintenance management records should be reviewed to determine the uniformity of the project. These records will help define the width of the travel lanes and the shoulders as well as the thickness of the materials in each of these features. The maintenance history will not only help define the types of treatments that have been placed on the roadway section but will also help identify the location of pavement problems along the section. Large maintenance expenditures associated with one or more sections of the project may indicate subgrade, base or surfacing problems. Defining the type of past maintenance activities performed on the existing roadway will help determine the probable locations of pavement performance problems (subgrade, base, surface, shoulders, etc.)

Visual Condition Survey

The current condition of the pavement should be evaluated to help determine the cause of pavement distress associated with the project. As a starting point TxDOT's Pavement Management Information System (PMIS) data over the last several years should be consulted. A current visual condition survey by one or more experienced individuals should be conducted. The PMIS visual evaluation forms or suitable District methods may be employed to collect the data. As a minimum it is important to define the type, extent and degree of the distress types listed below.

1. Rutting or permanent deformation
2. Raveling
3. Bleeding
4. Alligator or fatigue cracking
5. Transverse or thermal cracking
6. Longitudinal cracking-wheel path or fatigue cracking
7. Longitudinal cracking-near edge of pavement (moisture change in clay soils)
8. Potholes or localized failures
9. Edge drop-off/disintegration
10. Maintenance/rehabilitation alternatives

A brief description of the types of pavement distress and their associated causes is provided below. The potential causes of the pavement distress (structural design, materials selection, materials design, construction, etc.) will help identify appropriate maintenance and rehabilitation strategies.

Rutting - Rutting or permanent deformation is a depression in the cross section of the pavement in the wheel path and can be caused by poor quality hot mix asphalt or base course as well as inadequate structural capacity which can cause rutting due to subgrade permanent deformation. In general, the greater the width of the rut the deeper the source of the problem in the pavement section. A wide rut depth indicates either a weak subgrade or base course. A very narrow rut is associated with the asphalt mix quality.

Raveling - Raveling is a loss of fine and/or coarse aggregate from the surface of an asphalt pavement. While raveling is normally associated with asphalt mix, aggregate loss for seal coats can also be defined as raveling or shelling. In asphalt mixtures, raveling may be an indicator of stripping, low asphalt content, changes in aggregate gradation, inadequate compaction, or asphalt binder hardening. Loss of chips or stones from seal coats can be caused by low asphalt binder shot quantities or excessive application of chips during construction as well as inadequate rolling during construction. Cool and cold weather under high traffic volumes as well as stopping and turning traffic movements accelerate chip loss.

Bleeding - Bleeding is the presence of excess asphalt binder on the surface of an asphalt pavement. Bleeding in asphalt mix surfaced pavements is often associated with high binder content, changes in aggregate gradation and stripping of the asphalt binder from the aggregate. High traffic volumes and high pavement temperatures accelerate this problem. Bleeding in seal coats or chip seals typically results from excess asphalt binder and perhaps inadequate stone quantity placed during construction. High traffic volumes and high pavement temperatures as wll as stopping and turning traffic movements accelerate this behavior.

Alligator Cracking - Alligator or fatigue cracking is an indication that the pavement structural design is inadequate for the traffic volumes and weight using the facility. In general, the base or surfacing materials are of insufficient thickness. This distress is located in the wheel paths where traffic loading occurs. On some pavements, alligator cracking may start as a series of small transverse cracks only in the wheel paths. In other pavements, alligator cracking may start as a discontinuous longitudinal cracks located at the edges of the wheel path. Alligator cracking can occur simultaneously with wide ruts attributed to weak subgrade or base layers.

Transverse Cracking - Transverse cracking is an indicator of cracking associated with the environment or shrinkage of materials in sub-layers of the pavement. Rapid temperature drops starting at relatively low temperatures or large daily temperature changes, cause transverse cracking in asphalt pavements. Older asphalt mixes with more oxidized binders will crack more readily than others. Traffic volumes will increase the frequency of transverse cracks. Temperature cracking is more prevalent in West Texas. Transverse cracking is also commonly associated with the use of portland cement stabilized bases and subgrades. After hydration and drying these materials will shrink and crack in a transverse cracking pattern. Lime stabilized materials can also cause transverse cracking.

Longitudinal Cracking-Wheel Path - Longitudinal cracking can occur at the edges of the wheel path. This type of cracking can be the initiation of alligator cracking and hence an indication of inadequate pavement structural section for the amount of traffic using the facility (fatigue cracking). This pattern of cracking is often associated with the top-down form of fatigue cracking and is not continuous along all wheel paths. Another cause of longitudinal cracking at or near the wheel path is segregation caused by the laydown machine. Segregation of the hot mix asphalt near the center line of the paved width as well as at the edges of the "tunnels" moving the hot mix asphalt from the paver hopper to the horizontal auger can cause longitudinal cracking. This form of longitudinal cracking is associated with construction practices and not pavement structural inadequacy. Reflection cracking from construction joints in the lower levels of hot mix asphalt pavement and base courses can cause longitudinal types of cracking. Reflection cracking resulting from cracks present in the old pavement may also be a source of longitudinal as well as transverse cracking.

Longitudinal Cracking-Near Edge of Pavement - Longitudinal cracks often form within 6 to 8 ft. of the paved surface edge in areas where subgrade soils have relatively high plastic indices (greater than about 30). This type of cracking pattern is very typical in the area east of a line from San Antonio to the Dallas-Ft. Worth area (greater central Texas). These cracks are associated with volume change of soils caused by fluctuations in moisture contents (shrinkage cracking).

Potholes - Potholes are localized pavement failures caused by a number of factors including inadequate structural design, materials selection and design and construction problems. Potholes can be an indication of the overall adequacy of the pavement, and their presence as well as general location should be noted.

Edge Drop-Off/Disintegration - One of the common problems associated with FM roadways subjected to energy development and production traffic is edge drop-off and disintegration. Roads with narrow travel lanes or narrow shoulders experience considerable amounts of drop-off and disintegration under truck traffic. Shoulder drop-off often leads to paved surface raveling or disintegration from the outside edge inward.

Maintenance/Rehabilitation Alternatives

After performing the visual condition survey of the project pavement it is often helpful for the surveyor to list potential maintenance and rehabilitation alternatives. These recommendations should be accompanied by photographs or videos of the roadway as well as a summary of distress type, extent and severity information.

Ground Penetrating Radar

Ground penetrating radar (GPR) has proven to be a useful tool to determine the thickness moisture conditions of the various pavement layers along a section of highway. This device can be operated at highway speeds, the data reduction is fast and the output from the GPR is relatively easy to interpret. The GPR can be used to verify the historical records indicating the types and depths of the various layers of the pavement along a project. It is not unusual to identify discrepancies associated with historic records with this device. The types of materials and their thicknesses are important inputs for determining maintenance and rehabilitation alternatives.

Level Two

Level Two activities, in addition to the activities for Level 1, involve the use of a Falling Weight Deflectometer (FWD) and/or Dynamic Cone Penetrometer (DCP). This information is vital to help determine the load capacity of the existing pavement structural section as well as the individual materials that comprise the structural section. Both these devices require traffic control for data collection. The FWD must stop for a short period of time at a particular location and the DCP requires a work crew for up to an hour at a fixed location.

The FWD provides information on the overall load carrying ability of the pavement structural section as well as an indication of the load carrying ability of each pavement layer. Stiffness or resilient modulus values for the various materials comprising the structural layer can be determined through a process of backcalculating layer modulus values from the surface deflections.

The DCP will help determine the relative stiffness of the base, subbase and subgrade materials. Correlations are available to allow for the determination of stiffness values such as CBR or modulus for the different pavement materials. The DCP is particularly helpful in identifying weak layers within the pavement structure.

Level Three

Level Three activities include those from Levels One and Two and require the field sampling and laboratory testing of the existing pavement materials. Samples of the subgrade, subbase, base and surfacing materials are obtained and laboratory tests are performed to determine their load carrying ability. Additional laboratory tests can be conducted to determine appropriate stabilizers (portland cement, emulsified asphalt, foamed asphalt, fly ash, lime-fly ash, etc.) and stabilizer contents to use with the existing pavement materials.

Pavement rehabilitation alternatives can be provided from this information as described in Reference 9. The recommended alternatives will describe the different types of materials available and their recommended thicknesses.

Recommended Levels of Investigation

Three levels of data gathering are described above. The level of activity and the cost of each level of investigation differ from one to another. Recommended levels of investigation associated with anticipated maintenance/rehabilitation activities are provided in Table 1.

Table 1. Guide to Level of Investigation According to Anticipated Corrective Action.

Anticipated Maintenance/Rehabilitation	Pavement Condition Investigation	
	Level	Activities
Routine Maintenance	1	Historic records/visual condition & perhaps GPR
Preventive Maintenance	1 & 2	GPR/FWD & perhaps DCP
Rehabilitation	1, 2 &3	Field sampling and laboratory testing

TRAFFIC-STEP 3

Traditional Methods

Traditional information on traffic volumes and loads on Texas highways is obtained by the Traffic Planning and Programming (TP&P) Division of TxDOT. Traffic growth in areas of the state with oil and gas development and production activities has been very fast and nearly impossible to capture with conventional methods historically used by TP&P. Quick estimates of traffic flow may be obtained from TP&P using traffic maps for statewide planning or PMIS. However, these maps take time to publish and do not account for rapidly changing nature of oil and gas development. Financial and workforce limits have prevented TP&P from obtaining accurate, timely traffic projection on these energy sector impacted roadways.

Some Districts impacted by this large increase in total traffic and heavy vehicle have performed their own traffic studies which allow for more accurate estimations of existing traffic volumes. The existing traffic volumes are then used to forecast future traffic for project design purposes. Methods have been developed that allow for traffic estimates depending upon the number of wells being developed in a given area. While these are useful, well development may take place rapidly in some areas ahead of the ability to program maintenance or rehabilitation projects.

Special Studies

While individual districts can measure existing traffic and forecast future traffic volumes, they do not have the equipment to determine the axle weights of vehicles. The TxDOT Maintenance Division and the Bryan District have performed limited studies to determine the number and weights of trucks required for the development and production of oil and gas from single wells.

A systematic approach was taken to determine the traffic loads for pavement design (ESALs) in connection with the development and operation of typical horizontal, hydraulically-fracked oil and gas wells in the Eagle Ford Shale, Permian Basin, and Barnett Shale regions of the state. The general process to determine ESALs for individual wells involved the following:

- The number of trucks per well activity phase was determined, from pad construction to drilling, fracking, and operation of a typical well over a 20-year period. Truck volumes were estimated by relying on information in the literature from around the country as well as information gathered by TxDOT and data available from the FracFocus database (for the amount of water and sand used for fracking operations).
- The axle weight distribution was estimated for the truck types used for each phase of well development. This was accomplished by analyzing weigh-in-motion data which was tied to video logs of the weighed vehicles.
- The axle weight distribution for each truck type used was applied to the number of trucks per well development or operation phase and, with this information, the AASHTO road test equations were used to estimate the number of ESALs for each phase.
- The total number of ESALs from the development and operation phases was determined for arriving and departing trucks from an average well in the Eagle Ford Shale, Permian Basin, and Barnett Shale formations. The variation in traffic generated per well in different regions is due to factors such as the amount of horizontal drilling versus vertical

drilling, whether the products are primarily gas or oil, and the likely presence of pipelines. From the arriving and departing ESALs the larger value was used for pavement design. This information is found in Table 2.

- The data in Table 2 were used to calculate the number of wells served on a given route in each region for ranges of 20-Year ESALs. Thus, a maintenance supervisor or engineer can use a well count in an area to estimate the traffic level for design purposes.

Table 2. ESALs per Well during Development and Operation for Different Texas Formations (14).

	Barnett Shale Region	Eagle Ford Shale Region	Permian Basin Region
Number of trucks (Development)	5,413	15,170	10,324
ESALs per well after 20 years (trip to well) of operation	5,804	10,641	6,151
ESALs per well after 20 years (trip from well) of operation	3,823	13,694	10,792

Next, it was necessary to determine the ATHWD for the Triaxial check of the pavement section for the 4-layer cases where flex base is used. This estimate was provided by Figure 2 which shows the relationship between ATWHLD and ESAL.

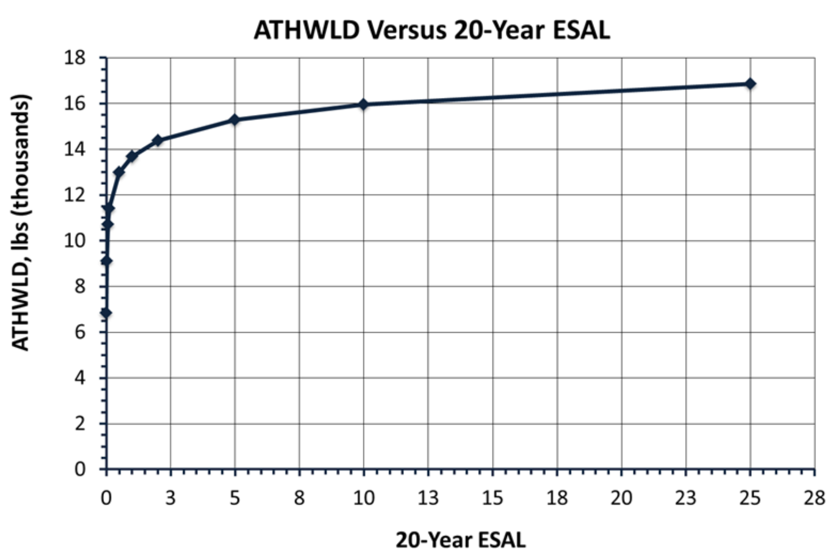

Figure 2. ATHWLD for 20-Year ESAL Level.

Additional information is being collected to improve the prediction of traffic information for pavement design purposes associated with the development and production of oil and gas wells.

Information from TxDOT WIM stations, well site traffic counts and industry data will form the primary information for improving traffic estimates for pavement thickness design purposes.

Uncertainty

Considerable uncertainty exists with predicting traffic associated with oil and gas development and production. Recent studies (14) have greatly improved the understanding of the traffic loads required to complete and operate wells in different parts of the state. While the traffic generated by a well dissipates with the distance from the well, the amount of concurrent traffic on routes dictates that pavement design be based assuming no dissipation. In other words, the amount of wells in a given area should generate a steady flow over the affected pavements so that dissipation is minimized. In addition to this fundamental information, a considerable number of other very important factors need to be considered and estimates should be made based on the "best" available information at the time of the decision making.

Geopolitics

World geopolitics to a large degree dictates the price of crude oil and hence the economic viability of developing energy sources of different types. For example, oil embargos and war in the middle-east have created large increases in crude oil prices at different times in history. When the price of crude oil is high, alternate energy sources are explored and oil and natural gas from economically challenging geological formations is produced. Production of hydrocarbons from oil sands, tar sands and shale are relatively expensive as compared to the more historically available hydrocarbons. At some price point for crude oil, development and production activities from high priced formations will be slowed or stopped. Horizontal drilling and hydraulic fracturing are more costly than more conventional operations and hence dependent on geopolitics and the price of crude oil. Some industry analysts indicate that crude prices near $70 per barrel could slow production in some parts of Texas. Less well development and production will reduce traffic and road damage.

Well Site Development

Well site development includes the haul and placement of base course type materials for access roadways and drilling/production pads. The length of the access road will determine the amount of materials and the haul vehicles necessary to transport these materials. Poor soils such as those in south Texas require more roadway structural section materials than in the west Texas area.

Drilling and production from multiple wells on one site is becoming more practical with the horizontal drilling operations. Two and three wells per pad are not uncommon. The use of multiple wells on one pad decreases the overall amount of site preparation materials.

The largest truck traffic generators for site preparation include the following:

1. Construction equipment (dozer, excavator, maintainer, rollers, crane)
2. Construction material haul
3. Water haul
4. Vacuum trucks

Truck traffic generation for site preparation is typically of the order of 500 loaded trips.

Drilling Operations

The nature of the drilling operation impacts the traffic required to service the operation. Some of the variables include:

1. Number of wells per pad
2. Depth of well
3. Length of horizontal drilling
4. Number of “pay zones”
5. Well spacing
6. Vertical versus horizontal wells

If two or more wells are drilled per pad, only one move-in and move-out is required for the drilling equipment. The greater the depth of the well and the greater the length of horizontal drilling, the greater the truck traffic required to service the well site.

Multiple “pay zones” or geologic formations are available in both south and west Texas. Usually one pay zone is used for production at a given time. Exceptions do exist. If multiple pay zones can be placed in production from one pad over a period of time, a reduction in site preparation traffic is possible.

Well spacing can also impact traffic generation from a given highway. The general trend in the industry is a reduction in well spacing as fields are developed.

The south Texas drilling operations are nearly all horizontal drilling operations with hydraulic fracturing. West Texas drilling operations are approximately 60 percent horizontal and about 40 percent vertical. The Permian basin activities are changing from vertical to horizontal drill activities. As discussed below, horizontal drilling with hydraulic fracturing of the formations requires a considerable amount of truck traffic support as compared to more traditional vertical drilling operations.

The largest truck traffic generators for the drilling operation include the following:

1. Drill rig
2. Drill pipe and casing
3. Drilling mud and chemicals
4. Drilling cuttings/waste material
5. Vacuum trucks and clean-up
6. Water
7. Portland cement
8. Fuel

Some of the heaviest loads associated with oil and gas development and production is associated with moving drilling rigs. Special haul vehicles with permits are used by most drilling contractors. Without proper haul vehicles, drill equipment loads can be very large.
The depth of drilling and the length of horizontal drilling will impact traffic generation during drilling operations. The variability of track traffic associated with increased depths and lengths or vertical and horizontal drilling operations is small as compared to traffic associated with the completion operation.

Completion Operations

Completion operations can generate significant truck traffic. The significant variables affecting completion operations are listed below:

1. Vertical drilling
2. Vertical and horizontal drilling
3. Length of horizontal drilling
4. Schedule for well re-stimulation activities

The completion of horizontal wells with hydraulic fracturing can generate up to 20 times the truck traffic associated with conventional vertical well completion operations. Hydraulic fracturing operations require the use of considerable equipment, proppants, chemicals and water transport. One to two thousand loaded trucks can be used in completion operations associated with each well.

The longer the length of the horizontal drilling operation, the greater the fluid and proppant demand for the well. The amount of fresh water used for hydraulic fracturing operations (fracking) is considerable and can easily be in the thousands of gallons. Movement of fresh water by truck is avoided if at all possible due to the large cost of trucking. Temporary pipe lines from surface water tanks (ponds) or local water well sites are used whenever possible. Some operating companies install water wells for the drilling operations.

Flow back water (salt water) associated with the hydraulic fracturing operation can be as high as 60 percent of the fresh water utilized. The salt water must be hauled from the well site and disposed in a suitable injection well permitted for this liquid.

Fresh water has a specific gravity of 1.00 (8.33 lbs. per gal.) while the flow back and production salt waters can have specific gravities in excess of 1.2 (10 lbs. per gal.). Fresh water trucks can haul of the order of 6,500 gal. at a legal load limit of 80,000 lbs. This same truck with salt water would have a weight of 91,000 lbs. Salt water haul vehicles typically have smaller tank sizes and haul at legal weight limits.

Production of oil and, to a lesser extent, gas drops off rapidly in some wells drilled into shale pay zones. Re-stimulation of the well may be necessary after about 3 years. The traffic generated by this re-stimulation activity is typically equal to that associated with the original completion operation as re-fracturing of the pay zone will likely be necessary. Secondary and tertiary completion operations can also be anticipated in these wells over the next 20 years.

The significant generators of truck traffic associated with well completion operations include the following:

1. Hydraulic fracturing equipment and materials
    a. Blenders and pumps
    b. Sand storage and transport
    c. Chemical storage and transport
    d. Miscellaneous equipment including manifold, iron truck, frack tanks and fuel transports
2. Fresh water

3. Flow back water
4. Well re-stimulation operations

As noted above the number of truck loads for completion operations can vary considerably from well to well depending upon a number of factors.

Production Operations

Typically the operating companies prepare the well for production and complete the infrastructure to deliver the hydrocarbons to market. Well-heads, pump-jacks, piping, tankage, power supply and other miscellaneous items are installed in the immediate area of the well. In the south Texas area, few infrastructure facilities were in place to deliver the oil and gas from the wellhead to markets. Truck haul of the crude oil and flaring of the gas is common at many of these well sites for periods of time that can be of the order of 6 to 12 months.

The infrastructure for hydrocarbon deliver in the Permian Basin is in place in many areas as this is an older oil and gas producing area. This is also somewhat true for the roadway infrastructure as many highways have been widened and strengthened over the years of oil and gas development and production.

The rapid development of the infrastructure in the south Texas area has been massive and is on the order of billions of dollars. This infrastructure includes pipelines for oil and gas collection and transport, gathering stations, pumping stations, separation facilities, etc. The truck traffic generated from the installation of this infrastructure has not been defined to date.

Summary

The projection of truck traffic in the near term (3 to 5 years) and in the long term (20 years) is very difficult due to the many variables that cannot be controlled. The important variables and the generators of truck traffic have been identified above.

Table 2 and Figure 2 provide a simplistic approach for predicting traffic on roadway facilities. The method ties truck traffic for a given roadway to well numbers served by that roadway. The number of wells served by the roadway can be estimated based on the GIS maps showing past well locations and expected well development based on permits issued to oil and gas operating companies. Conversations with oil and gas producing companies indicated that well development typically starts within weeks or a month of the issuance of the well permits by the Texas Railroad Commission. Therefore the prediction of traffic development in the near future and more distant future will be difficult and should be based on expected development in the area served by the roadway under study. The development of traffic for a given roadway segment should be based on consideration of the following key factors:

1. Geopolitics
2. Price of crude oil
3. Site Development
   a. Length of roadways required to service well operations
   b. Wells per pad
   c. Well spacing
4. Drilling Operation

   a. Number of pay zones
   b. Vertical versus horizontal drilling
   c. Length of vertical and horizontal drilling operations
   d. Wells per pad
5. Completion Operations
   a. Length of vertical and horizontal drilling operations
   b. Hydraulic fracture water haul requirements
   c. Salt water disposal haul
   d. Schedule for re-stimulation of wells
   e. Number of pay zones
6. Production Operations
   a. Infrastructure development needs
   b. Haul of crude oil

Once the number of wells is estimated for a given roadway segment, this number can be multiplied by the ESAL and ATHWLD predicted per well. The assumptions used to estimate the ESAL per well site is given below:

1. Horizontal drilling
2. Hydraulic fracturing
3. Fresh water haul by truck
4. Salt water haul by truck
5. Crude oil haul by truck for some period of time

The traffic data obtained by this process should be considered conservative.

THICKNESS DESIGN-STEP 4

Background

Pavement rehabilitation practices associated with the repair of oil and gas development and production activities typically involve some type of pavement strengthening operations either performed by maintenance forces or a maintenance or construction contract. These operations include deep patches, widening of the roadway or rehabilitation of the entire roadway section. The determination of the structural thickness of the pavement is therefore an important part of selecting a maintenance or rehabilitation alternative for a particular roadway. The most reliable and traditional means is to contact the district pavement engineer and perform an extensive study of the roadway. However, practicality and time constraints preclude this in many cases, so a simplified catalog approach to pavement design has been developed.

The types of rehabilitation operations currently used by TxDOT Districts are summarized in reference 7. Rehabilitation on oil and gas affected roads often takes the form of full-depth reclamation with strengthening. Typically, the existing road surface and base are mixed together and, if the road needs widening, are spread over a wider area. Depending upon the condition of the material and the structural requirements, the reclaimed material may be either stabilized or non-stabilized. Once the FDR operations have been completed either a new flexible base can be applied with either a two-course surface treatment (2CST) or an asphalt concrete (AC) overlay for the wearing course (14). This is referred to as a 4-layer pavement (surface, flex base, FDR, and subgrade). In some instances, a 3-layer pavement (surface, FDR, and subgrade) may be used with a stabilized FDR (cement, asphalt emulsion, or foamed asphalt) used as a base course with no flexible base and with a 2CST or an AC overlay surface.

The use of portland cement at a level of 2 to 3 percent (cement modified) with the full depth recycling operation is common. Districts increasingly are using asphalt emulsions and foamed asphalt as binders in full depth recycling operations. Flexible base is often placed on top of the full depth recycling layer. Some districts have used portland cement as a stabilizer with the new flexible base material. The use of portland cement stabilization as a base course is discouraged if a surface treatment or thin hot mix asphalt layers are to be used as a wearing or surface layer as reflection cracking may occur.

FPS Design

The current TxDOT Flexible Pavement Design (FPS), augmented by the Modified Texas Triaxial Check, is recommended for use on all energy impacted roadways. This procedure has a long history of use in Texas.

Simplified Method

A simplified method of structural design has been developed to provide quick estimates for pavement layer requirements. Two design catalog tables (4-layer and 3-layer pavement) have been prepared with the use of TxDOT's FPS program and mechanistic models. Since the 4-layer pavements have flex base, these were also subjected to a Triaxial Classification check to preclude subgrade shear failure. Table 3 presents the material properties used to develop the design catalogs.

The two tables (Tables 4 and 5) containing the design catalogs are provided to allow for easy determination of layer thicknesses given several fixed parameters. The tables can be used by field operational personnel to quickly determine the thickness requirements for deep patches, shoulder widening activities and/or full width pavement rehabilitation activities. Reference 11 can be used to better understand the methodology used to develop these design tables.

Table 3. Materials Property Inputs for Pavement Structural Design Curves.

Layer	Material	Properties		Thickness, in.	Comments
		Resilient Modulus, psi	Triaxial Class		
Surface	Surface Treatment			Less than 1	2-course surface treatment
	Hot Mix Asphalt	500,000		4 and 6	
Base	Flexible Base	50,000		6 to 12	New flex base with FDR subbase
	High* Stabilization	300,000		6 to 11	No flex base
	Medium* Stabilization	200,000		6 to 13	
	Low* Stabilization	100,000		6 to 15	
Subbase	FDR-salvaged	50,000		6 and 8	No stabilizer

Table 3. Materials Property Inputs for Pavement Structural Design Curves. (Cont'd)

Layer	Material	Properties Resilient Modulus, psi	Triaxial Class	Thickness, in.	Comments
	FDR-PC	150,000			
	FDR-Asphalt	100,000			
Subgrade		7,000	5.8		
		10,000	5.0		
		20,000	3.0		

FDR--Full Depth Recycling
FDR-PC--Full Depth Recycling with portland cement as modifier (2 to 3 percent)
FDR-Asphalt--Full Depth Recycling with asphalt emulsion or foamed asphalt as stabilizer
*High, Medium and Low levels of Base Stabilization indicates the amount of asphalt binder (emulsion or foam) used to obtain high, low or medium modulus (stiffness).

For each traffic level presented in Table 4, there are 4 subbase stiffness and thickness levels considered: 6-inch and 8-inch cement treated and 6- and 8-inch flex base or asphalt-emulsion treated base. Pavement surfaces include a 2-course surface treatment as well as 4 and 6 inches of asphalt mix. In general, it is advisable to avoid the use of the 2CST and 4-inch thick asphalt surfaces in high traffic (> 3 million ESAL) pavements as structural rutting and fatigue cracking may occur. However, 2CST may be used with 12 inches of flex base over a stiff subgrade for traffic up to 4 million ESAL. At higher traffic levels hot mix asphalt is the preferred surface material and a minimum thickness of 4 inches is recommended for heavy traffic. At traffic above 5 million ESALs the FPS-21 thickness design procedure should be used to determine the necessary pavement section.

As an example using Table 4 (4-layer) to determine the structural requirements for a pavement, assume a road is located in the Eagle Ford Shale (soft subgrade, modulus < 7 ksi) with 125 oil wells in the immediate area. The existing roadway has an adequate amount of surface and base to allow for a FDR treatment to a depth of 8 inches. With the cement modified (CM) option, the pavement section would be a two-course surface treatment (2CST) over 10 inches of flex base over 8 inches of cement modified subbase. This may be compared with the asphalt emulsion or non-stabilized subbase option where 12 inches of flex base is required for the same surface and same thickness of subbase. These are illustrated in Figure 3. Surface treatments should not be used when predicted 20 year ESALs are at 3.0 million and above except in the case of a stiff subgrade where the allowable traffic may go up to 4.0 million ESALs.

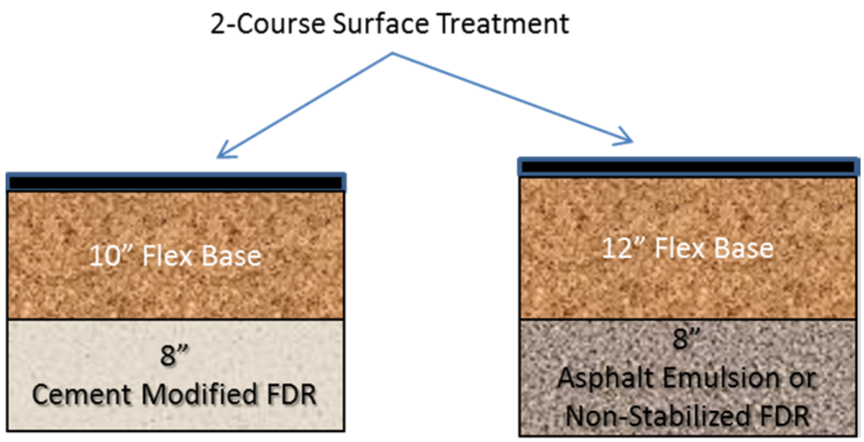

Figure 3. Comparison of Pavement Sections Using Table 4 for 2 Million ESAL, Soft Subgrade, and 8 inches of FDR.

The designs presented in Table 5 (3-layer) are for surfaces placed directly on stabilized FDR bases. The stabilization in this case may be cement modification, asphalt emulsion, or foamed asphalt. The traffic level categories are at the top of the table, and there are three cases of subgrade stiffness as in Table 4. In Table 5, the degree of stabilization is considered to be related to the stiffness. There are three levels of stabilized FDR base stiffness along the left side of the table: high (modulus = 300 ksi), medium (modulus = 200 ksi) and soft (modulus = 300 ksi). The stiffness of the FDR base will be dependent upon the amount of material passing the No. 200 sieve, the likely PI of the blended material, and the amount of stabilization used. Because of the stiffness and thickness of the FDR bases, all the sections presented in Table 5 passed the mechanistic criteria for rutting and fatigue.

An example for using Table 5 is to compare medium stiffness stabilized FDR base thicknesses for a road with 4 million ESAL, a medium stiffness subgrade for surface treatment, 2 inches of asphalt mix surface and 4 inches of asphalt mix surface. Reading the chart shows that the CST requires 10 inches of FDR, a 2-inch asphalt surface requires 9 inches, and a 4-inch asphalt surface needs 6 inches as seen in Figure 4.

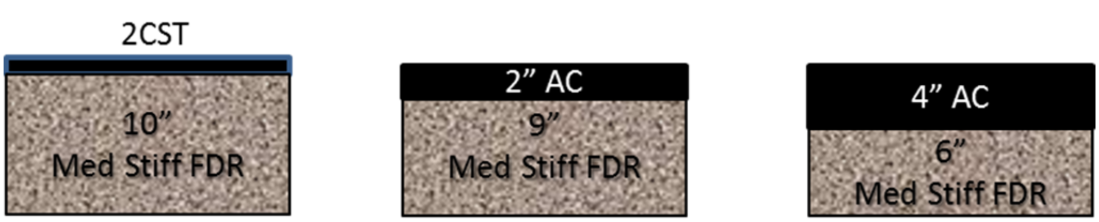

Figure 4. Comparison of Pavement Sections Using Table 5 for 4 Million ESAL, Medium Stiff Subgrade and Medium Stiff Stabilized FDR.

Table 4. Energy Sector Pavement Design Catalog for 4-Layer (Surface, Flex Base, FDR, Subgrade) Pavement. Numbers in table are Flex Base thickness in inches.

Traffic, ESAL	**<0.5 Million**			**0.5-1.5 Million**			**1.5-3.0 Million**			**3.0-4.0 Million**			**4.0-5.0 Million**			**>5.0 Million**
EF #Wells	**<10**			**10-90**			**90-200**			**200-270**			**270-340**			
PB #Wells	**<20**			**20-110**			**110-250**			**250-340**			**340-440**			Use Formalized Design
BS #Wells	**<40**			**40-210**			**210-470**			**470-640**			**640-810**			
	Eagle Ford (Subgrade Modulus < 7 ksi)															
Surface	2 CST	4” HMA	6” HMA	2 CST	4” HMA	6” HMA	2 CST	4” HMA	6” HMA	2 CST	4” HMA	6” HMA	2 CST	4” HMA	6” HMA	
CM 6”	11	7	6	12	8	6	12	9	7	-	-	7	-	-	7	
CM 8”	9	6	6	10	6	6	10	7	6	-	-	6	-	-	6	
AE/NS 6”	12	8	6	12	9	7	12	10	7	-	-	8	-	-	8	
AE/NS 8”	12	6	6	12	7	6	12	10	7	-	-	8	-	-	8	
	Medium Subgrade (Subgrade Modulus < 7 - 15 ksi)															
CM 6”	7	6	6	10	6	6	12	6	6	-	-	6	-	-	6	
CM 8”	6	6	6	7	6	6	10	6	6	-	-	6	-	-	6	
AE/NS 6”	12	6	6	12	6	6	12	6	6	-	-	6	-	-	6	
AE/NS 8”	12	6	6	12	6	6	12	6	6	-	-	6	-	-	6	
	Permian Basin (Subgrade Modulus > 15 ksi)															
CM 6”	6	6	6	6	6	6	10	6	6	12	-	6	-	-	6	
CM 8”	6	6	6	6	6	6	10	6	6	12	-	6	-	-	6	
AE/NS 6”	6	6	6	9	6	6	12	6	6	12	-	6	-	-	6	
AE/NS 8”	6	6	6	8	6	6	12	6	6	12	-	6	-	-	6	

BS #Wells: Number of wells serviced by road in the Barnett Shale.
PB #Wells: Number of wells serviced by road in the Permian Basin.
EF #Wells: Number of wells serviced by road in the Eagle Ford Shale.

CM 6” = Cement Modified FDR, 6 inches thick
CM 8” = Cement Modified FDR, 8 inches thick
AE/NS 6” = Asphalt Emulsion FDR or Non-Stabilized FDR, 6 inches thick
AE/NS 8” = Asphalt Emulsion FDR or Non-Stabilized FDR, 8 inches thick

Not Recommended - Premature Failure Expected

Table 5. Energy Sector Pavement Design Catalog for 3-Layer (Surface, FDR, Subgrade) Pavement. Numbers in table are FDR Base thickness in inches.

Traffic, ESAL	<0.5 Million				0.5-1.5 Million				1.5-3.0 Million				3.0-4.0 Million				4.0-5.0 Million				>5.0 Million
EF #Wells	**<10**				**10-90**				**90-200**				**200-270**				**270-340**				**Use Formalized Design**
PB #Wells	**<20**				**20-110**				**110-250**				**250-340**				**340-440**				
BS #Wells	**<40**				**40-210**				**210-470**				**470-640**				**640-810**				
	Eagle Ford (Subgrade Modulus < 7 ksi)																				
Surface	2CST	2” HMA	4” HMA	6” HMA	2CST	2” HMA	4” HMA	6” HMA	2CST	2” HMA	4” HMA	6” AC	2CST	2” HMA	4” HMA	6” HMA	2CST	2” HMA	4” HMA	6” HMA	
Stiff Base	8	6	6	6	9	7	6	6	10	8	6	6	-	8	7	6	-	8	7	6	
Med. Base	9	7	6	6	11	9	6	6	11	9	7	6	-	10	8	6	-	11	9	6	
Soft Base	11	9	7	6	14	11	9	7	15	12	10	8	-	14	12	9	-	15	12	9	
	Medium Subgrade (Subgrade Modulus < 7 - 15 ksi)																				
Stiff Base	7	6	6	6	8	7	6	6	9	7	6	6	-	8	6	6	-	8	6	6	
Med. Base	8	6	6	6	10	8	6	6	10	8	6	6	-	9	7	6	-	10	7	6	
Soft Base	10	8	6	6	13	10	8	6	13	11	9	6	-	12	10	7	-	13	10	7	
	Permian Basin (Subgrade Modulus > 15 ksi)																				
Stiff Base	6	6	6	6	7	6	6	6	7	6	6	6	-	7	6	6	-	7	6	6	
Med. Base	7	6	6	6	8	7	6	6	8	7	6	6	-	8	6	6	-	8	6	6	
Soft Base	8	6	6	6	10	8	6	6	10	8	6	6	-	9	7	6	-	10	7	6	

BS #Wells: Number of wells serviced by road in the Barnett Shale.
PB #Wells: Number of wells serviced by road in the Permian Basin.
EF #Wells: Number of wells serviced by road in the Eagle Ford Shale.

Stiff: E_{FDR} = 300 ksi
Medium: E_{FDR} = 200 ksi
Soft: E_{FDR} = 100 ksi

(red) Not Recommended - Premature Failure Expected

CONSTRAINTS-STEP 5

Selection of maintenance and rehabilitation alternatives are based on a number of engineering related factors as well as a wide variety of other considerations such as financial resources, workforce availability, equipment availability, materials availability, weather conditions, scheduling and traffic control.

Financial

Financial constraints include the amount of money available for maintenance and rehabilitation operations as well as the source of the money. Financial resources available on an annual basis for routine maintenance, maintenance division contracting, construction division contracting and special allocations are set from within TxDOT or directed by the state legislature. Financial constraints are typically the most significant limitations to selecting maintenance and rehabilitation alternatives. For example, certain types of allocated funding can only be used for rehabilitation and not routine maintenance.

If only limited money is available for routine maintenance, routine maintenance operations will be used to “hold” the roadway until more substantial funding is available. If special legislative funding becomes available, longer term more expensive rehabilitation alternatives may be selected depending on the condition of the roadway system.

Workforce Availability

Many districts have experienced a reduction in the available workforce for maintenance operations. This will limit the amount of routine maintenance operations that can be performed on roadways.

Districts heavily impacted by oil and gas development and production have made arrangements to use maintenance crews from other districts. The arrangements for sharing of personnel across district lines have been made at the District Level as well as a statewide program.

Equipment Availability

Some districts have reported the loss of key equipment necessary to efficiently repair damaged roadways. Cold milling machines and pulverizers/stabilizers are examples that were once part of District fleet equipment but are no longer available in certain Districts. Equipment sharing across District lines has been practiced in several locations of the state.

Materials Availability

Materials availability associated with the repair of damaged roadways has generally not been a problem. No asphalt binder shortages have been reported by the Districts. Some Districts have reported shortages of flexible base materials. This shortage may be more of a result of transportation limitations than material supply. Transportation of materials used for maintenance and rehabilitation of the roadways has been a problem in selected districts, because oil and gas development and production requires the transportation of considerable materials and products and has placed a high demand on transport vehicles as well as drivers. A shortage of truck drivers also exists throughout the state.

Weather and Scheduling

Weather conditions can influence the type of maintenance or rehabilitation alternative selected for a roadway. Pulverization, stabilization, placing new base course and placing a surface course should not be scheduled during cold/inclement weather unless emergency conditions exists. Certain asphalt binders do not perform well if placed in cold weather. For example, most asphalt emulsions should not be used in cold weather due to the potential for freezing or the inability to break. The use of cutback asphalt during cooler weather conditions is possible; however, cutback asphalt may cause problems with rutting and flushing during the hot summer months. Seasonal use constraints of different materials should be considered in the decision making process.

Traffic Control

Traffic control is difficult on narrow FM roadways and constrained right-of-ways. The maintenance and rehabilitation alternatives selected for repair of the roadway should consider traffic control issues. Typically traffic must be allowed on the project as a minimum in one direction at a particular time. Closing of roadways for short durations should be considered if access to landowners is provided. Roadway closing will allow for the maintenance/rehabilitation alternative to be completed in a relatively short period of time and result in a safer work zone as compared to working on only one half of the roadway at a given time. Notification of adjacent land owners and business is an important part of this approach.

MAINTENANCE

Data collected to this point in the decision tree will dictate the level of maintenance required; conversely, the level of maintenance selected may allow a lower level of data needed to make effective decisions depending upon the condition of the roadway.

R**OUTINE MAINTENANCE-STEP 6**

TxDOT's "Maintenance Planning Activities & Associated Function Codes" can be used as a general guide for selection of routine maintenance activities. The main activities are listed as shown in Table 6. More detailed descriptions of these activities can be located in the Maintenance Division's Code Chart 12 Guidelines. Reference 7 provides a summary of current maintenance practices used by the Districts impacted by oil and gas development and production according to the following methods:

1. Shallow patch
2. Deep patch
3. Level-up patch
4. Shoulder/edge repair

Table 6. TxDOT Maintenance Work Activity Function Codes for Flexible Pavements.

Function		Activity
Code	**Subcode**	
P01		Pavement Leveling
	211	Leveling or Overlay with Laydown Machine
	212	Leveling or Overlay with a Maintainer
	213	Leveling by Hand
	214	Leveling or Overlay with Drag Box
P02		
	252	Milling and Planning
	253	Spot Milling
P03		Base Repair
	110	Removal and Replacement
	120	In-Place Repair
P04		Spot Seal (Chip Seal) Coat
	232	Strip or Spot Seal Coat
	233	Fog Seal
	235	Microsurfacing
	265	Treat Bleeding Pavement
P05		Full Width Seal Coat
	231	Seal Coat
P06		Crack Seal
	225	Sealing Cracks
	325	Cleaning and Sealing Cracks
P07		Edge Maintenance
	270	Edge Repair
	455	Reshaping Unpaved Shoulders
P08		Pothole Repair
	242	Pothole Repair
P10		Adding or Widening Pavement
	245	Adding or Widening Pavement

Details relative to materials, materials quantities, crew size, equipment and productivity are provided in the Code Chart 12 Guidelines. Comments relative to successful use and problems encountered with these routine maintenance alternatives are also provided.

Routine maintenance operations are typically used to repair localized pavement problems to improve safety, provide a smoother riding surface and to delay more extensive maintenance or rehabilitation. Budget constraints and weather conditions sometimes require the use of routine maintenance under pavement conditions where more extensive maintenance or rehabilitation is needed. The use of various types of patches (shallow, deep and level-up for example) and shoulder/edge repair techniques including patching, strip seals and widening have been effective in delaying major maintenance or rehabilitation on roadways that are in reasonably good condition and carrying relatively low traffic volumes in the oil and gas development and production areas of the state.

Routine maintenance techniques shown in Table 3 and those identified in Reference 3 have been largely ineffective on roadways that are in poor condition and that carry high traffic volumes. Therefore, routine maintenance operation under these conditions should be viewed only as a temporary repair and more extensive maintenance or rehabilitation scheduled as funding and weather permit.

PREVENTIVE MAINTENANCE-STEP 7

This work is done to prevent the major deterioration of a pavement. Preventive maintenance techniques (Table 3) are typically associated with the use of seal coats (fog, chip and slurry or microsurfacing) and thin hot mix asphalt overlays. Texas has a long, successful history of using chip seals (seal coats) as a preventive maintenance tool.

For oil and gas development and production impacted roadways, the condition of the roadway is often in such poor condition that preventive maintenance techniques are not beneficial. Many of the impacted roadways are structurally deficient and preventive maintenance techniques do not significantly improve structural load carrying ability for a period of 3 to 7 years. In addition, many of the roadways are narrow and need to be widened.

Energy impacted roadways that are in relatively good condition and will be subjected to light volumes of truck traffic can often benefit from widening and the application of a chip seal (seal coat) across the entire pavement. Widening should be such that 12 ft. travel lanes are provided with a minimum of 2 ft. shoulders or a more desirable 4 ft. shoulder on each side of the pavement. The preventive maintenance alternatives described above have been used with some success to delay the need for rehabilitation.

The use of slurry seals or microsurfacing on roadways that are structurally deficient should be approached with caution. Chip seals (seal coats) are able to tolerate higher deflections and strains to failure than most slurry seals and microsurfacing materials.

The use of thin overlays (less than 2 inches) on roadways subjected to energy sector traffic should be approached with caution. High deflections on many of these roadways will cause premature cracking of the hot mix asphalt under moderate to heavy traffic volumes. TxDOT Overlay Design methods should be used to determine the thickness of overlay needed. In areas of relatively soft subgrades (south Texas) overlays may need to be 4 inches and greater. In areas of the state (west Texas) where subgrade strength is higher, overlays in the range of 3 to 4 inches may be suitable. Thin overlays should not be placed on structurally deficient pavements.

REHABILITATION-STEP 8

The types of rehabilitation operations currently used by TxDOT Districts are summarized in Reference 7. Typical sections involve the use of full depth recycling (FDR) to pulverize and widen the existing roadway, followed by the placement of a flexible base and asphalt bound surface. Full depth recycling (FDR) operations are sometimes performed without the addition of a stabilizer. The use of portland cement at a level of 2 to 3 percent (cement modified) with the full depth recycling operation is common. Some Districts have used asphalt emulsions or foamed asphalt as binders in full depth recycling (FDR) operations.

The materials produced from the pulverization and in some case the addition of stabilizers can be used as subbase materials. Typically 6 to 8 inches of subbase materials can be obtained from this operation. The depth of the recycling to produce the subbase will depend on the amount of granular and asphalt bound materials existing on the roadway, the depth of pulverization and the width the materials is to be placed (including shoulder widened area). Since the amount of granular and asphalt bound materials on many existing Farm to Market roadways is limited, some districts add new flexible base prior to stabilization to form this layer. Flexible base is typically placed on top of the full depth recycling layer in order to provide the desired thickness (Table 4). Some districts use portland cement as a stabilizer with the new flexible base material. The use of portland cement stabilization of the base course is discouraged if a surface treatment or thin hot mix asphalt layers are to be applied. Disintegration of the portland cement stabilized material may occur under high truck traffic volumes and loads.

Some districts are exploring the use of fully stabilized base courses using cement, asphalt emulsion, or foamed asphalt under the wearing surface as shown in Table 5. Cement stabilization should be used with caution due to possible reflective cracking and disintegration under heavy traffic.

Surface treatments or hot mix asphalt is typically used as surfaces on oil and gas development and production impacted roadways. Typically a double surface treatment is used on top of the new flexible base material. It is recommended that a minimum of 4 inches of hot mix asphalt be used in the south Texas Districts. It may be possible to use hot mix asphalt less than 4 inches on pavements with relatively low deflection.

Thickness designs for rehabilitation activities should be determined by TxDOT's FPS-21 thickness design method. A simplified method is available in this document (Step 4) if sufficient time or personnel are not available to perform the FPS design.

ECONOMIC ANALYSIS-STEP 9

First cost and life cycle costing should be performed on several maintenance and rehabilitation options. Budget, work force availability, equipment availability, materials availability, traffic control and weather or scheduling may eliminate some of the maintenance and rehabilitation alternatives under consideration.

Reference 12 is a simplified guide for performing first cost and life cycle costing. Ideally three to four maintenance/rehabilitation alternatives should be considered in this step of the process. This reference also includes a methodology for determining and incorporating "road user costs" into the economic analysis.

SELECTION OF ALTERNATIVE-STEP 10

This step of the process selects the maintenance or rehabilitation alternative to be used on a specific project. If life cycle costs for various maintenance or rehabilitation alternatives are within 10 percent of each other, the selection of the final alternative should be based on project considerations and District experience.

Prior to selecting the maintenance/rehabilitation option, it is useful to review the process shown in Figure 1 and the notes and calculations developed to support the decision.

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