project being cancelled if one sponsor develops budget problems. For example, the 1982 NTS was cancelled when the Research and Special Programs Administration was unable to honor its commitment to support that survey.

On the other hand, financial sponsorship by the user of a survey provides substantial leverage to ensure that the survey is responsive to the needs of the sponsor. The Census Bureau is continually under pressure from many federal agencies, Congress, state and local governments, and the private sector to accommodate many different and sometimes conflicting data requirements. Consequently, the greater control a user has over the funding for a survey, the more leverage the user has in determining the scope and content of that survey.

3. How should DOT coordinate and negotiate its requirements with the Bureau of the Census and other user agencies regarding transportation surveys?

Historically, DOT has always had an identifiable organizational unit with specific responsibilities for articulating the information needs of DOT and for coordinating interagency projects required to satisfy these needs. The resources currently assigned to this function have been cut back to the point that coordination, if done at all, is often accomplished by individuals in the various DOT agencies without reference to an organizational focal point within DOT. Consequently, opportunities for developing more efficient survey projects, articulating DOT data needs in interagency forums, and reducing the burden on respondents, have been diminished. Three options for improving the DOT's statistical coordination function are suggested: (a) creating a larger staff, (b) centralizing data responsibilities for census projects, and (c) making the program more visible to higher management.

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Methodology for Assessing and Predicting Pavement Performance in Oil Field Areas

JOHN M. MASON, JR., BRYAN E. STAMPLEY, and THOMAS SCULLION

ABSTRACT

A basic methodology for estimating the amount and type of oil field traffic on a selected roadway is outlined. The Texas Pavement Distress Equations were used to predict reductions in pavement service life caused by oil field truck traffic. The procedure used a case study example to identify and delineate major oil field activity centers. Several density maps were developed to depict the extent of drilling and production activity in the study area. Truck traffic generated in these centers was converted to 18-kip equivalent single axle load repetitions; these were analyzed for their effect on 6- and 10-in. surface-treated pavements. Resulting pavement service lives were compared for various measures of pavement distress (pavement serviceability index, rutting, alligatoring, flushing, and raveling). This technique can be used to anticipate resurfacing intervals and rehabilitation requirements.

The Arab Oil Embargo of 1973 spurred an increase in oil field development throughout the nation. In the oil-rich regions of Texas, this increased activity had an adverse effect on many light-duty rural highways. These highways were intended to service low volumes of passenger cars and light trucks and were not built to withstand the impact of the load-intensive, special-use oil field traffic.

The Texas State Department of Highways and Public Transportation (TSDHPT) found it necessary to determine the effects of oil field development on rural highways. Phase I of the research identified traffic and vehicle characteristics associated with oil field development and estimated a reduction in pavement service life due to this specialized user (1).

Phase II of the research involved developing and applying a method of assessing the current effects, and predicting the future effects, of oil field development on any particular rural highway. The method is in the form of a computer program, Oil Field Damage Program, fully described in Research Report 299-2 (2). Although it was developed as a means of predicting the present and future effects of oil field development, the same basic principles can be used to develop programs for examining the effects of other types of load-intensive, special-use traffic.

STUDY PROCEDURE

An overall picture of oil field development was necessary to estimate and describe oil field traffic on a specific roadway. Once an impacted region was identified, individual roads were delineated within the major producing areas. The affected roadways serve both intended-use traffic and the special-use oil field traffic. Because an existing roadway must therefore accommodate an increased demand, the anticipated design life is shortened considerably. A methodology for assessing and predicting the effects of oil field development was prepared so that the resulting change in pavement performance could be defined.

The study procedure shown in Figure 1 illustrates the need to identify specific activity centers, describe the associated traffic characteristics, and estimate the effect of changes in traffic demand on a roadway pavement.

Oil field activity in a region is assessed by the following steps:

1. Develop a base map of the study area.
2. Identify (plot) related oil field activity centers.
3. Prepare a composite of the impacted area and surrounding areas of influence.

Base Map

The base map used for this study (Figure 2) is of Brazos County and was supplied by TSDHPT. The county boundaries and pertinent roadways were traced on a 24 x 36-in. sheet of Mylar paper at a scale of 1 in. equals 2 miles. This map size was satisfactory for showing minor roads and streets, creeks, rivers, ponds, and lakes, as well as lines of latitude and longitude. The lines of latitude and longitude orient the base map and serve as an initial map grid system.

State regulations governing oil well density were taken into consideration when the size of the map grid system was developed. In Texas oil field activity is regulated by the Texas Railroad Commission, which typically allows a maximum density of one well to each 40 acres (3). At the selected map scale each sector represents 284 acres and could contain a maximum of seven oil wells.

Oil Field Activity Centers

The map grid system divides the county into sectors. The number of activity centers for any given oil field related activity was determined for each sector. Then each activity was plotted on a separate density map. The resulting density maps show the extent of a particular activity. Oil field activity was segregated into three general types: service companies, wells drilled, and producing wells.

Service companies in each sector were located by using telephone books and city maps. A system was established to classify and tabulate the number of service companies in each sector, as shown in Figure 3.

The status and location of existing oil and gas wells throughout the state were available from large-scale maps prepared by private agencies. Depending on the density of activity, a county may need to purchase maps of several sections to obtain full coverage. Pertinent map information includes property ownership, lease information, and geographical data, such as roads, rivers, and lines of longitude and latitude. The number and status of oil wells were determined for each map sector and tabulated. Then the sum of oil wells drilled in each sector was calculated and used to develop the drilling location density map shown in Figure 4.

The number of producing wells in each sector was also available from the completed activity identification sheets. These sums were used to develop the map showing the density of producing oil wells shown in Figure 5.

The density maps convey information on the relative levels of activity in the area and the amount of growth in oil field activity. When the density maps for service companies, wells drilled, and producing wells were overlaid one on the other (Figure 6), oil field activity centers became apparent. Because these maps were developed for April 1981, and updated as of July 1, 1982, the movement and development of new oil wells could be readily identified. Documenting oil production on a regular basis helps monitor oil field traffic activity in an area. Iden-

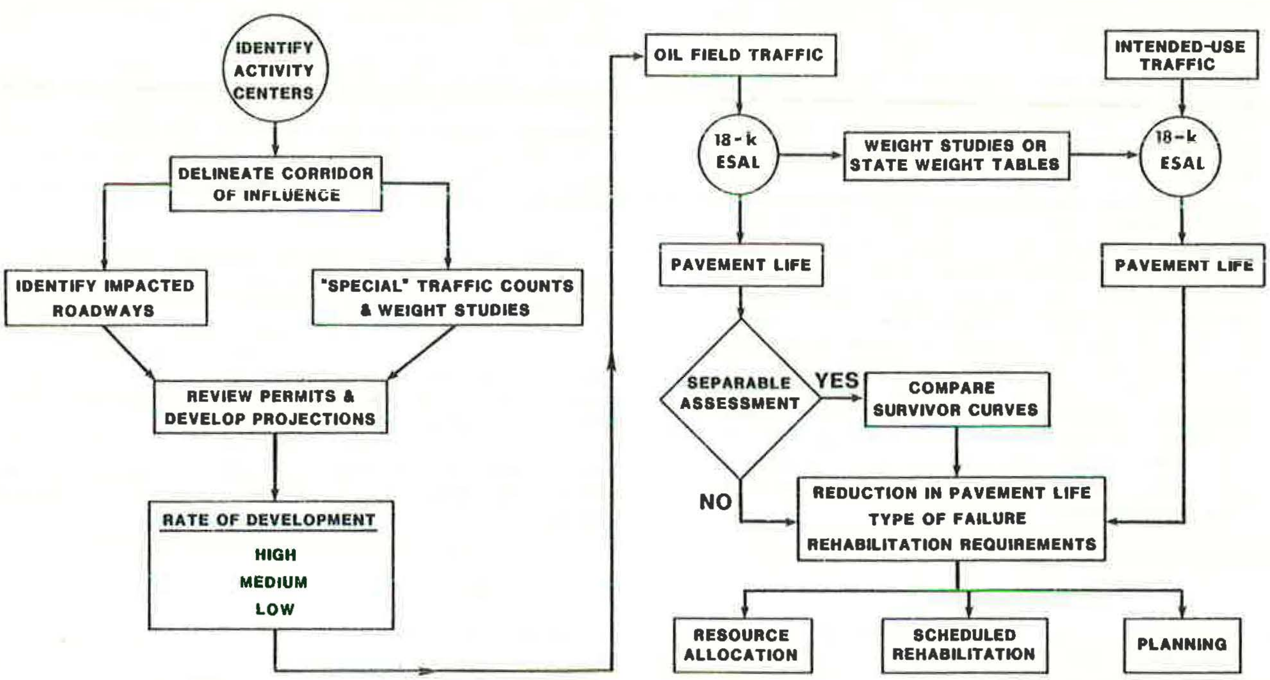

FIGURE 1 Phase II research procedure.

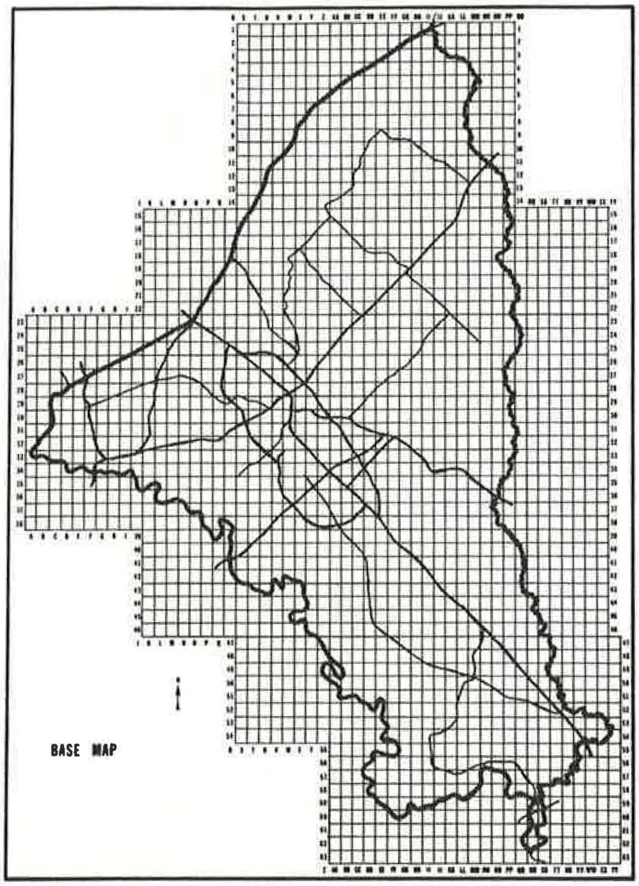

FIGURE 2 Base map (Brazos County).

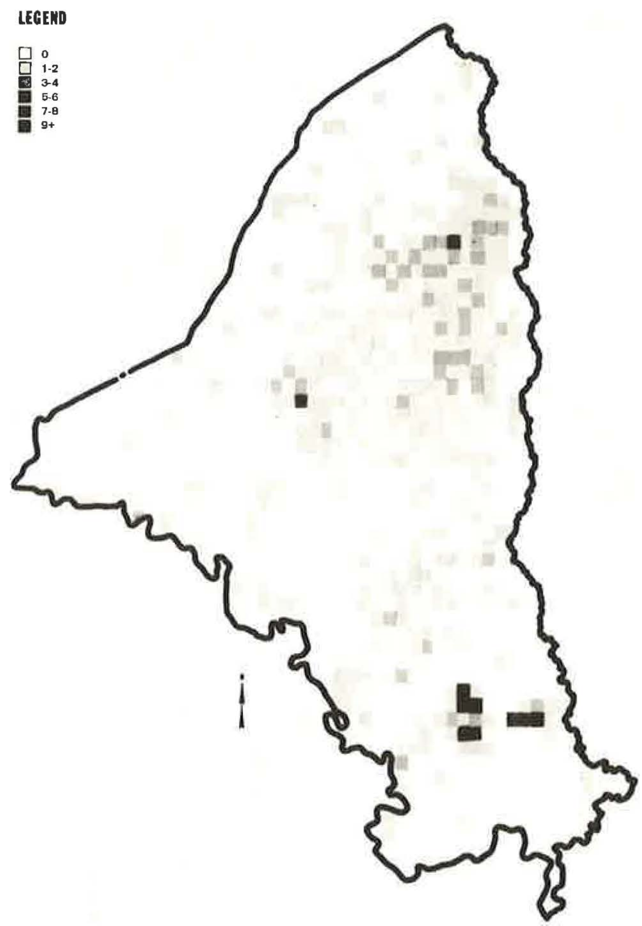

FIGURE 4 Drilling location density map.

Sector		Number of Service Companies
F	36	18
	37	18
K	32	1
L	32	2
	33	2
P	42	8
R	25	2
	28	1
	29	1
	31	1
S	29	1
	30	6
	31	11
	32	3
U	27	2
	31	1
	38	1
V	24	1
	27	3
	32	2
	33	3
	34	1
	35	1
W	26	3
	27	3
	29	4
	30	6
	31	1
X	24	1
	25	1
	27	19
	28	1
	30	3
	32	3
	33	2
	34	1
Y	25	1
	27	19
	28	1
	32	2
Z	24	1
	32	3
	33	2
AA	25	3
	31	3
	32	3
	33	1
	35	3
BB	30	1
	32	3
	35	2
	36	2
	37	2
CC	22	2
	23	1
	34	3
	36	4
DD	22	6
	34	1
	38	5
EE	33	1
	38	2
FF	38	1
GG	19	9
	20	3
KK	23	1
PP	10	5
QQ	37	1
WW	56	5

FIGURE 3 Summary sheet for locations of service companies.

tifying this additional traffic demand is essential in assessing current pavement conditions and in planning maintenance and rehabilitation strategies.

Case Study Example

Three major centers of oil field activity are shown in Figure 6, and because the Kurten area was the largest, it was selected for closer study. This region contains several low volume roads. When the activity centers map was overlaid on a TSDHPT county map, a light-duty, surface-treated road [farm-to-market (FM) road 2038] was found to be the primary roadway serving the Kurten oil field area.

To estimate the amount of oil field traffic using FM-2038, an area of influence for the road was established, as shown in Figure 7. Basically all traffic within this area of influence uses FM-2038 when entering and exiting the area. It is helpful to think of the area of influence as being analogous to a tributary watershed. Traffic was visualized as flowing from the far reaches of the influence area down small tributary roads and emptying into the main stream, FM-2038, before leaving the area. Vehicles were assumed to travel on the most direct and best roads available, avoiding major natural obstructions.

TEXAS PAVEMENT DISTRESS EQUATIONS

The AASHO Road Test conducted in Ottawa, Illinois, in 1960 has been a major source of pavement perfor-

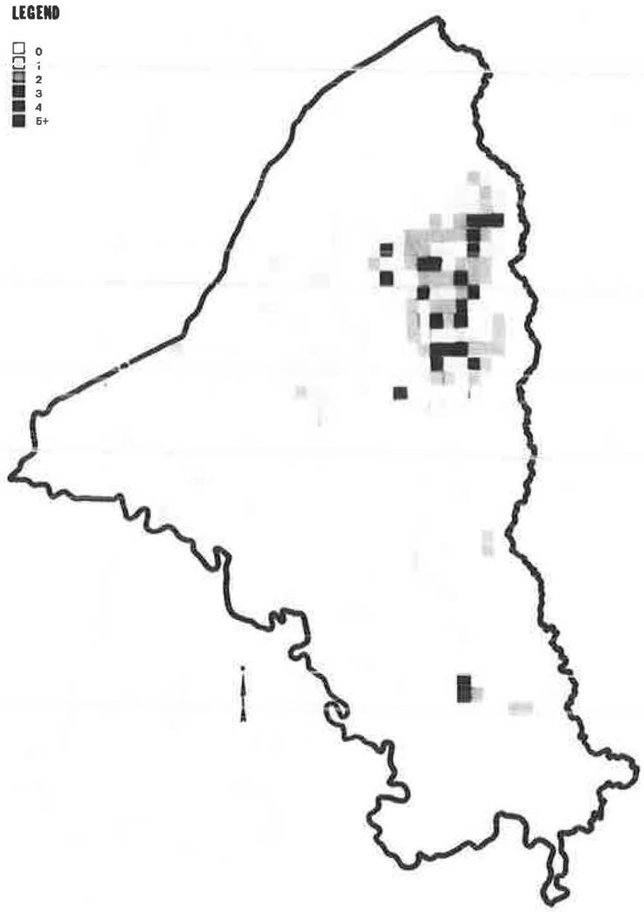

FIGURE 5 Producing oil well density map.

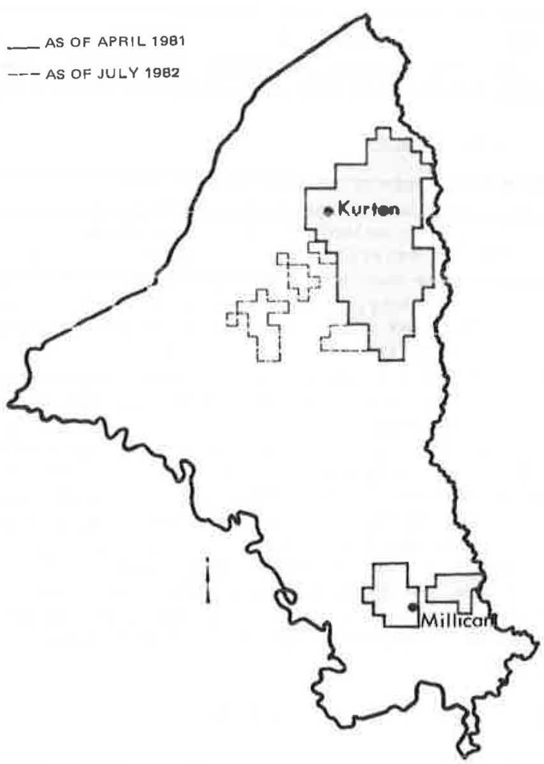

FIGURE 6 Location of activity centers.

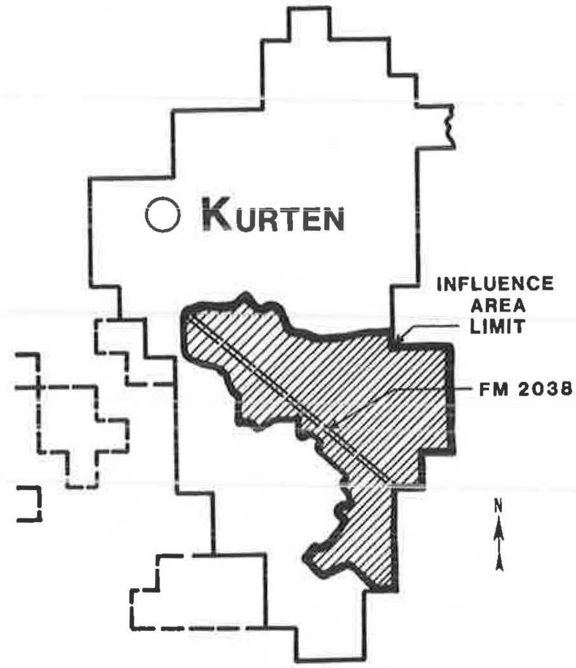

FIGURE 7 Limit of FM-2038 influence study area.

mance data. Because the AASHO Road Test equation was developed from data collected on flexible pavements with a minimum 2-in. asphalt surface course, it did not yield reasonable predictions of pavement life for the surface-treated pavements considered in this study.

Texas began maintaining a flexible pavement data base in 1972, with the ultimate goal of developing a series of equations. These equations would provide performance models for various types of flexible pavements in Texas. Pavement distress equations were developed for the following pavement distress types: alligator cracking, transverse cracking, longitudinal cracking, rutting, raveling, flushing (or bleeding), and patching. Equations were also developed for ride quality [present serviceability index (PSI)] and pavement score (PS). Pavement score is a composite index that describes overall pavement condition as a function of pavement distress and loss of ride quality.

Correlation coefficients (R^2) for the Texas Pavement Distress Equations generally range from 0.30 to 0.60. The overall reliability is expected to improve as pavement condition monitoring continues and pavement utility techniques and familiarity improve. The current versions of the equations, nonetheless, do more closely replicate the actual performance of Texas surface-treated pavements (4).

ASSESSMENT CASE

One objective of this project was to use the Texas Pavement Distress Equations through a program entitled, Oil Field Damage Program, to assess the condition of a roadway pavement under oil field traffic. This objective was satisfied by using the prepared density maps to estimate the traffic demand placed on the roadway in a major oil field area. The assessment period for FM-2038 was from July 1978 to July 1982. Initially FM-2038 was a 6-in. surface-treated pavement. In July 1978 it was reconstructed using a cement-stabilized subgrade with a 10-in. surface-treated pavement section.

Oil well ownership maps as of July 1982 showed a total of 285 producing wells in Brazos County. Drilling permit records for the county from the Texas Railroad Commission showed that 154 oil wells had been drilled between July 1978 and July 1982. Therefore, 131 wells were producing oil before the July 1978 reconstruction of FM-2038.

To estimate the number of oil wells developed within the FM-2038 influence area during the 4-year study period, it was assumed that oil drilling activity was uniformly distributed throughout the three major activity centers and that the probability of a well being drilled within any influence area was equal to the ratio of the influence area to the total area of the major activity centers.

Approximately 22 percent of the wells drilled in Brazos County during the 4-year study period occurred within the FM-2038 influence area. The percentage is the ratio of the influence area (35 sectors) to the total area of the major activity centers (160 sectors). Therefore, during the 4-year study period, 34 oil wells were assumed to be drilled in the area that affects FM-2038.

However, not all wells drilled in the county produced crude oil. The drilling density map (Figure 4) indicated that a total of 55 oil wells had been drilled within the FM-2038 influence area as of July 1982. Information from the production density map (Figure 5) showed that 46 of those wells (83.6 percent) were actually producing. Using this 83.6 percent success rate, 28 oil wells were assumed to be actually producing within the FM-2038 influence area during the 4-year period.

ASSESSMENT OF OIL FIELD DEVELOPMENT

To illustrate the use of the Texas Pavement Distress Equations as an assessment tool, two computer runs were made for FM-2038. The first run assessed the present condition of the 10-in. pavement after 4 years of oil field activity. The second assessed the condition of a theoretical 6-in. pavement subjected to 4 years of oil field activity. The simulation assumed that the 1978 reconstruction had only restored the pavement to a 6-in. thickness. The effect of a 1978 cement stabilization of the subgrade was included by changing the subgrade plasticity index from 23 percent to 12 percent.

Evaluation

Results obtained from the two computer runs were used to answer the following questions:

1. What is the current condition of FM-2038, a 10-in. surface-treated pavement serving 28 wells?
2. How much additional damage would have been inflicted on FM-2038 if the pavement had been only rehabilitated as a new 6-in. surface-treated pavement?
3. What pavement distresses are expected under intended-use traffic?
4. What pavement distresses are particularly sensitive to oil field truck traffic?

The various distress measures that were calculated using the Texas Pavement Distress Equations are summarized in Table 1. Limiting distress values are tabulated for each distress type. A comparison of the intended-use and oil field-use distress values demonstrates markedly that oil field truck traffic reduces pavement service life.

Figures 8-13 show the performance of a 6- and 10-in. pavement under intended-use and oil field traffic. Each figure represents estimated changes in pavement distress levels over time. The initial distress measure assumes a newly reconstructed pavement section. Pertinent limiting values are also shown for each type of distress.

Pavement performance is rated as either a measure of severity or area of distress. Both ratings should be examined to obtain a true description of pavement condition. In certain circumstances, small areas of localized intense distress, such as those caused by poor construction techniques, may inaccurately reflect overall pavement condition. Such areas, however, should be identified and remedied because they are aggravated by load-intensive, oil field truck traffic.

Because the intent of this study was to demonstrate the utility of the analysis methodology, selection of the critical rating for the different distress types was based on which rating (area or

TABLE 1 Estimated Distress Values for FM-2038 (July 1982)

Distress Type	Distress Measure[a]	Limiting Distress Value	Intended Use	Oil Field Use
Ride quality	P.S.I.	1.5	4.15	3.56
Pavement score	P.S.	35.0	90.5	29.0
Rutting	Area	50.0	8.0	61.2
	Severity	30.0	3.5	51.0
Alligator cracking	Area	50.0	0.0	23.8
	Severity	50.0	0.0	47.0
Raveling	Area	80.0	1.7	41.6
	Severity	30.0	3.8	59.2
Flushing	Area	80.0	4.5	61.3
	Severity	30.0	5.2	66.1

[a]Pavement performance is rated as either a measure of severity or an area of distress.

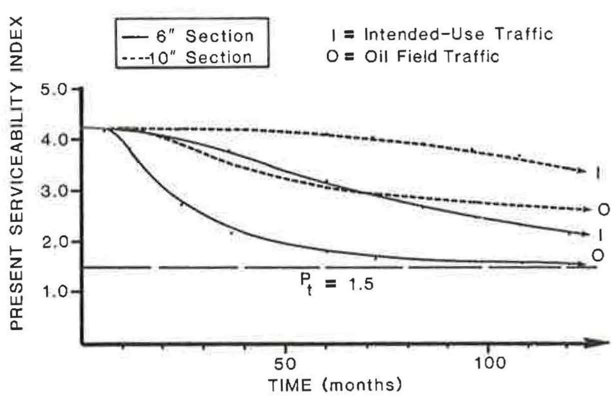

FIGURE 8 Present serviceability index versus time.

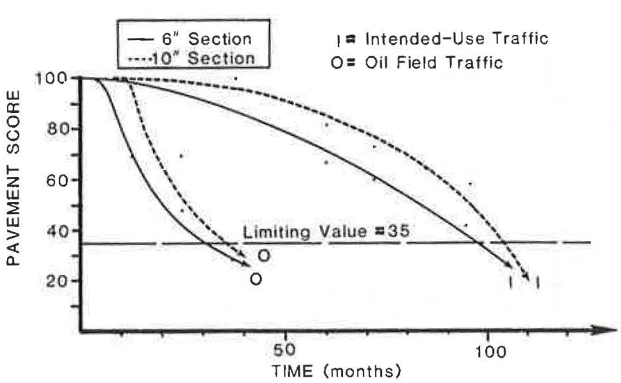

FIGURE 9 Pavement score versus time.

severity) reached its limiting value first (Table 1). Only in the case of rutting did the actual area of pavement distress approach its critical limit before the severity rating (depth of rutting) exceeded its limit. For all other distress types, the severity rating value reached its critical limit before the area rating value was exceeded.

Results

1. Current condition of 10-in. pavement. Figure 9 demonstrates the reduced service life due to increased traffic demand. The limiting pavement score of 35 was projected to occur after approximately 102 months (8.5 years); instead it was reached after only 41 months (3.4 years), which represents a 60 percent reduction in its normal life. Severe rutting and alligator cracking had been predicted, as well as excessive flushing and raveling.

A visual site inspection made in October 1982 generally confirmed the severe flushing and raveling predictions. Localized rutting was observed along the roadway length; however, alligator cracking was minimal. The cement-stabilized subgrade may be responsible for the indications of favorable strength. The visual inspections were based on standardized identifications of distress types described in the Highway Pavement Distress Identification Manual (5).

2. Expected damage to 6-in. pavement. The results indicate, as would be expected, that the thinner pavement reaches its limiting value in less time. However, one pertinent observation from each diagram (Figures 8-13) is that percent reduction in service life appears constant for each distress type for both the 6- and 10-in. pavements. Table 2 summarizes the loss of service time and categorically demonstrates the similarities in actual overall percent reduction.

3. Expected intended-use pavement distress. The pavement distress program can be used to predict service life under normal traffic conditions and to assist in selecting a desired pavement thickness. The distress limits for rutting area and flushing and raveling severity are reached in a 7- to 8-year time period. The 6-in. pavement appears susceptible to severe rutting, reaching its critical limit in 32 months.

4. Pavement distresses sensitive to oil field truck traffic. Oil field truck traffic induces rapid development of pavement distress. The reductions in pavement service life are shown in Figures 8-13 and summarized in Table 2. Traffic associated failures such as flushing and raveling are non-load-associated failures, whereas rutting and alligatoring on the thin 6-in. pavement shows sensitivity to repeated increases of equivalent axle loads.

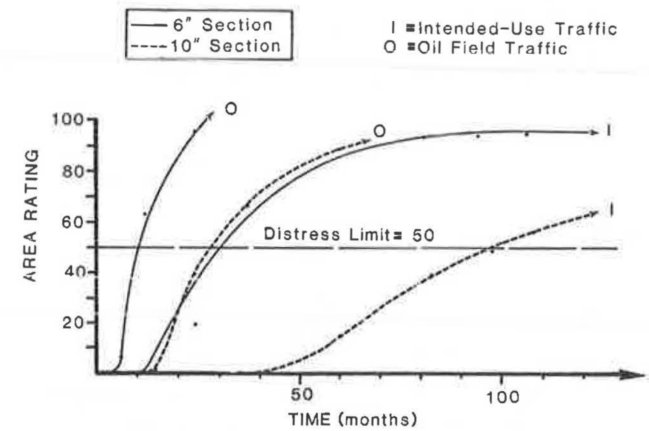

FIGURE 10 Rutting area versus time.

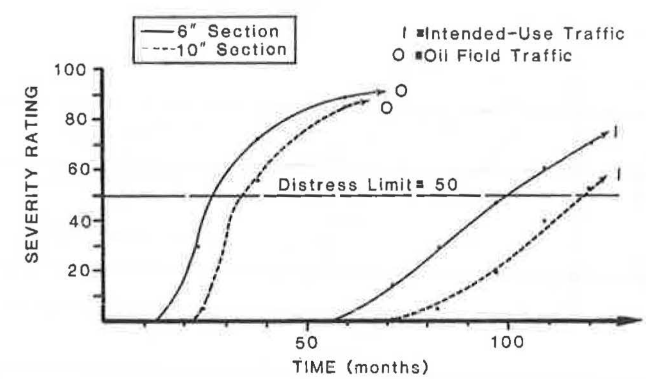

FIGURE 11 Alligatoring severity versus time.

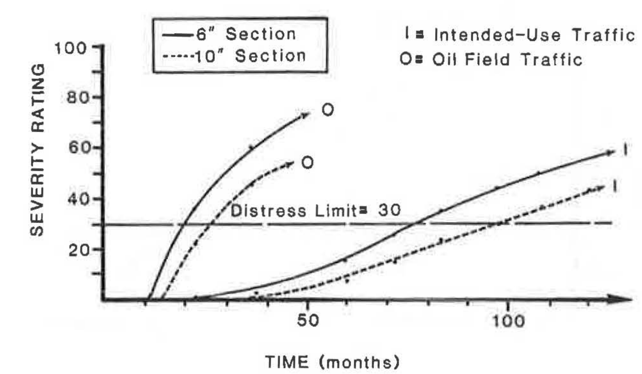

FIGURE 12 Raveling severity versus time.

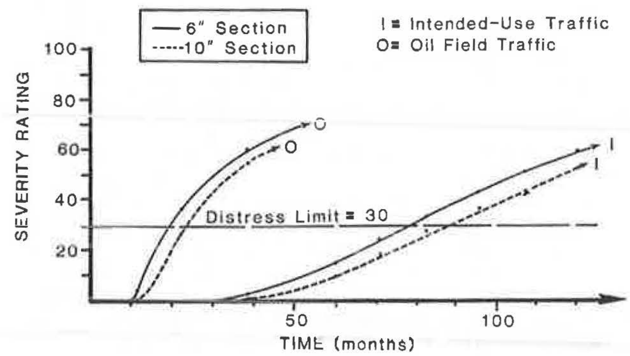

FIGURE 13 Flushing severity versus time.

TABLE 2 Comparison of Reduction in Pavement Service Life

	10-In. Pavement		6-In. Pavement	
Distress Type	Loss of Time[a] (months)	Reduction (%)	Loss of Time[a] (months)	Reduction (%)
Pavement score	104 - 41 = 63	61	97 - 31 = 66	68
Rutting	88 - 35 = 53	60	32 - 14 = 18	56
Alligatoring	116 - 50 = 66	57	99 - 35 = 64	65
Raveling	96 - 23 = 73	76	80 - 21 = 59	74
Flushing	88 - 22 = 66	75	80 - 20 = 60	75

[a]Time to failure under intended-use traffic minus time to failure under intended use plus oil field traffic equals loss of pavement service time.

PLANNING SCENARIO

Another objective of the project was to demonstrate the use of the Texas Pavement Distress Equations to predict the condition of a pavement under future levels of oil field development. Projections of future pavement condition are imperative in anticipating needed financial resources and in distributing allocated funds. This study's estimates of pavement service life provide a basis to predict the impact of future oil field activity on roadways.

Future oil field development along FM-2038 was selected as the case study example for the planning scenarios. A 5-year planning horizon was used to demonstrate the use of the pavement distress program. The study period begins at the conclusion of the previous assessment case study problem, July 1982, and will continue until July 1987.

Rate of Oil Field Development

Because the rate of oil field development fluctuates in an area, three general activity rates were defined: low, medium, and high. The actual number of wells drilled as well as the rate of drilling varies. However, both the magnitude and the rate can be estimated based on records maintained by the Railroad Commission (RRC) of Texas.

Records of drilling activity in Brazos County from July 1977 to July 1982 served as the basis for the general activity rates. The 15th, 50th, and 85th percentile conveniently segregated the drilling rates into high (six wells per month), medium (three and one-half wells per month), and low (one well per month) activity. Table 3 summarizes these three levels of drilling activity.

TABLE 3 Summary of Drilling Rates and Traffic Conditions for FM-2038 Influence Area

	Low	Medium	High
Drilling Rates for Brazos County			
Wells per year	12	42	72
Wells per month	1	3.5	6
Drilling Rates for FM-2038 Influence Area			
Wells per year	2	6	12
Months per well	6	2	1
Traffic Conditions (18-kip ESAL Repetitions)			
Intended use	25,600	25,600	25,600
Oil field	15,683	49,166	99,383
Intended use plus oil field	41,283	74,766	124,988

The three levels of development translate into drilling rates of 12, 42, and 72 wells per year. Applying the influence area ratio of 22 percent and a success rate of production of 83.6 percent, two, six, and twelve wells per year were calculated as the rate of development in the influence area. Table 3 also summarizes the rate of oil well activity and presents the resulting 18-kip equivalent single axle load (ESAL) repetitions for the 5-year analysis period. The analysis includes the projected total annual wells drilled and the actual production expected for each rate of development. The calculation of the resulting 18-kip ESAL repetitions has been reported completely elsewhere (1,2).

Prediction of Effects of Development

To illustrate the prediction capabilities of the Texas Pavement Distress Equations, several computer runs were made on a reconstructed, 10-in. surface-treated pavement section. The program was run for an intended-use traffic condition and at low, medium, and high traffic-use rates for the future development cases.

Evaluations

The results demonstrate the capability of anticipating pavement performance under varying rates of oil field development. Figures 14-19 show the performance of a 10-in. pavement under the three rates of development. The expected intended-use condition is

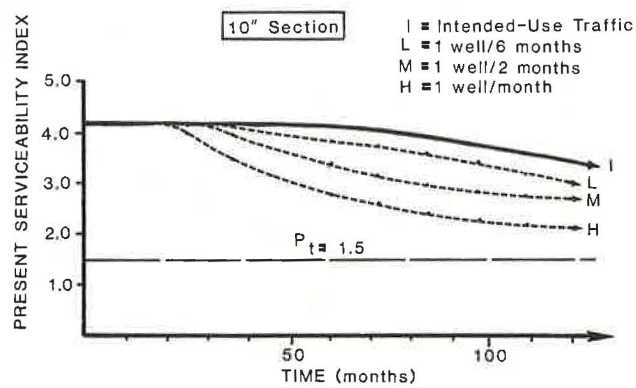

FIGURE 14 Present serviceability index versus time.

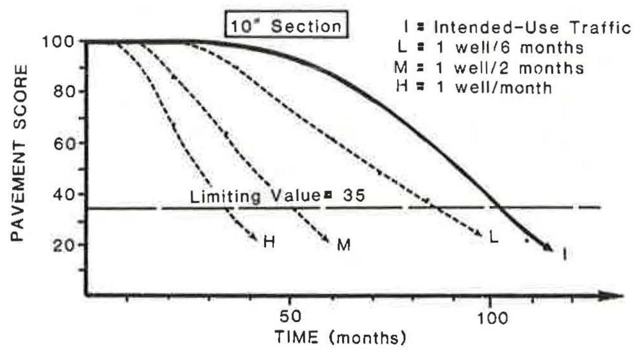

FIGURE 15 Pavement score versus time.

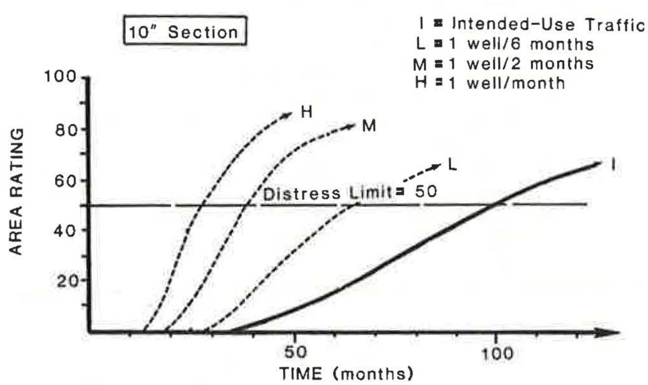

FIGURE 16 Rutting area versus time.

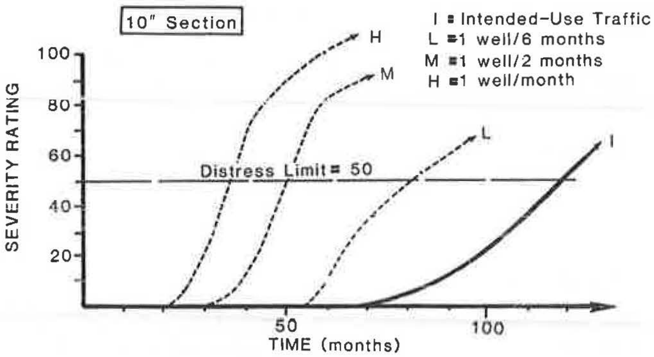

FIGURE 17 Alligatoring severity versus time.

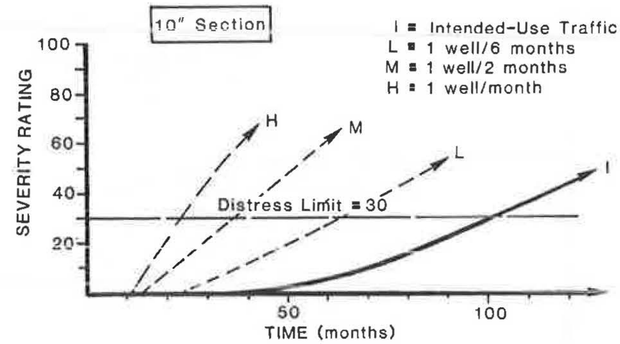

FIGURE 18 Raveling severity versus time.

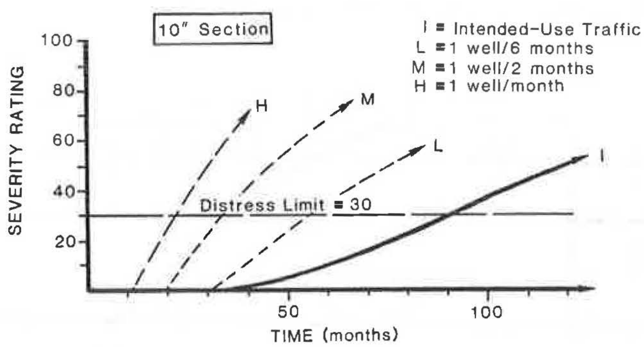

FIGURE 19 Flushing severity versus time.

also shown. Because the results of the previous assessment case indicated that FM-2038 would require reconstruction, the planning example assumed a rehabilitated pavement section. The pertinent limiting values for each type of distress are shown for the critical measures of performance rating.

The primary purpose of including these results in this project was to demonstrate the potential of using the overall methodology as a planning tool. Although the rate of oil field development varies among regions and fluctuates over time, general trends can be documented in site-specific areas.

The results of the planning scenarios indicate that even under low rates of development (two wells drilled per year in a known area of crude deposits), the service life of a 10-in. pavement section can be reduced. A review of the pavement score diagram (Figure 15) shows an overall potential loss of 16 months under a low oil field development rate. Although this loss of service life is not as dramatic as for higher activity rates or as detrimental as it might be for thinner pavements, Figures 16-19 demonstrate the specific distress problems that need to be anticipated.

Load-associated distresses, such as rutting and alligatoring, could result in reducing the expected service life by at least 3 years. Traffic-related measures of performance, such as raveling and flushing, also indicate a reduction in roadway utility of about 3 years. Again, these reductions are based on the conservative low rates of oil field development.

Predicting future conditions assists with planning appropriate maintenance as well as selecting adequate and economic pavement thicknesses. A reduction in pavement life is inevitable on any roadway; however, the effects of increased site-specific axle load repetitions cannot be ignored. Identifying and quantifying future levels of expected reduced service life can also be used in justifying requests for additional maintenance and rehabilitation funds.

CONCLUSIONS AND RECOMMENDATIONS

The presence of oil field traffic on a roadway causes a substantial reduction in expected pavement life. A 60 to 75 percent loss of predicted service life is possible on thin surface-treated pavements. The actual amount of increased pavement distress is a function of pavement thickness, average daily traffic, percentage of trucks, several environmental factors, and subgrade characteristics. To evaluate the effects of oil field traffic under various conditions, a methodology has been developed for assessing and predicting site-specific and regional impacts.

The Texas Pavement Distress Equations (Oil Field Damage Program) can be used to evaluate the current condition of an existing roadway or to predict its distress levels under future traffic conditions. Several rehabilitation strategies can then be examined. In the future, alternative pavement thicknesses can be analyzed to determine their long-range maintenance and reconstruction needs.

It is recommended that the primary use of this research be at the local state highway district level. The site-specific activity is first observed at the local level. If the district maintains density maps that reflect current activity, the engineer can readily identify the impacted roadways. The influence area could be delineated and monitored to anticipate future serious pavement failures.

At present, the development of the density maps requires manual manipulation and drafting of oil field related plans. However, to improve the comprehensiveness of the overall methodology for statewide use, current research is being conducted to create computer plotted density maps directly from computerized permit and drilling records.

On the state level this technique can be used to help the department allocate funds by locating roads that are in need or soon will be in need of maintenance or reconstruction monies. The versatility of the program not only allows the highway agency to predict where work will be needed but also to indicate the type of work required and when it will be required.

In future research, other special-use activities that impact the Texas highway system beyond its original intended use will be identified. The traffic characteristics and axle loads of trucks used by the timber, grain, and gravel industries are also atypical. Their isolated demands differ from those of vehicles associated with normal operation situations. To make the most effective use of planning strategies for pavement rehabilitation, site-specific data also need to be collected and analyzed for these unique truck demands.

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