field investigation into vehicle operating costs carried out by TRRL in Kenya in 1971-1973, and it was designed to complement that study.

The vehicle performance study provides a new set of relations for estimating vehicle speed and fuel consumption. The severe terrain on which the study was conducted in St. Lucia produced equations for estimating speed of a different order of magnitude than the existing Kenya relations. A method has been evolved to make use of these two sets of relations to provide realistic estimates of vehicle speeds for intermediate physical and environmental conditions. The fuel-consumption relations derived from the St. Lucia study provide improved estimating equations over a larger range of operating conditions.

The major differences between the two sets of user survey relations are the significantly higher effect on spare parts and tire consumption of a deteriorating bitumen-surfaced road compared with a gravel road of the same surface roughness and the lower rate of depreciation of heavy vehicles.

The two sets of relations have been combined and modified to make them suitable for inclusion in the new TRRL road transit investment model (RTIM2) (2). The equations used, together with limiting values, where applicable, are given in a separate paper by Parsley and Robinson in this Record. Full details of the data collected and analyses performed are given in TRRL reports (3,4).

ACKNOWLEDGMENT

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REFERENCES

1. H. Hide, S.W. Abaynayaka, I. Sayer, and R.J. Wyatt. The Kenya Road Transport Cost Study: Research on Vehicle Operating Costs. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, TRRL Rept. LR 672, 1974.
2. L.L. Parsley and R. Robinson. The TRRL Road Investment Model for Developing Countries (RTIM2). U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, TRRL Rept. LR 1057, 1982.
3. G. Morosiuk and S.W. Abaynayaka. Vehicle Operating Costs in the Caribbean: An Experimental Study of Vehicle Performance. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, TRRL Rept. LR 1056, 1982.
4. H. Hide. Vehicle Operating Costs in the Caribbean: Results of a Survey of Vehicle Operators. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, TRRL Rept. LR 1031, 1982.

Investigation of Effects of Oil Field Traffic on Low-Volume Roads

JOHN M. MASON, JR., AND THOMAS SCULLION

A conceptual framework is presented for analyzing the effect of heavy axle loads on light pavement sections. By using models specifically developed for surface-treated pavements, a reduction in pavement life is estimated. These models of pavement distress and serviceability have been developed by using regression analysis of pavement condition data collected over a seven-year period on thin pavements in Texas. The utility of the pavement distress analysis and conceptual argument is demonstrated through a case study example of oil well truck traffic. Results of this study assist in identifying the reduction in pavement life and additional life-cycle costs associated with the special-use traffic. The problems associated with oil field exploration and development are not unique but are similar in many respects to the impact of other load-intensive, commercially important hauls such as coal, grain, and cotton.

The oil embargo of the early 1970s dramatized the dependence of the United States on foreign oil production. Curtailment of crude shipments demonstrated that oil-producing nations are a primary source of economic control. The unfavorable consequences of reliance on foreign oil imports encouraged our country to strive for energy self-sufficiency. In an attempt to realize this independence, oil exploration is being accelerated, dormant wells are being rejuvenated, and trapped deposits are being reclaimed. These successful ventures have increased domestic production throughout the oil pool area of the Gulf states and have resulted in the enjoyment of the benefits of economic growth. Unfortunately, an adverse effect of this intense activity has been the physical destruction of light-duty roadway pavements serving the productive oil fields.

Low-volume rural roads in oil-producing areas were not initially constructed to endure the impact of intense oil field truck traffic. Thus, a condition of persistent rehabilitation was not anticipated under normal operating situations, and complete pavement restoration costs were not normally accounted for in the planning of maintenance. Since typical traffic characteristics and usual vehicle distributions are not applicable to roadways that carry oil field traffic, there is a need to determine the definitive elements of oil field traffic demand.

The Texas State Department of Highways and Public Transportation (TSDHPT) found that it was incurring considerable additional expense in keeping these highways open to traffic and rebuilding many of them once the oil field work had moved elsewhere. These additional expenses created a greater demand for state maintenance and rehabilitation funds. This problem led to the funding of a project between TSDHPT and the Texas Transportation Institute (TTI). The main objective of the project is to provide a means of accurately predicting the additional life-cycle costs being incurred.

The project is being broken up into the following phases. The first phase deals with quantifying the traffic levels and axle loadings associated with the development work. The second and current phase involves defining a procedure by which reductions in pavement life can be calculated. The third and future phase involves estimating the additional life-cycle costs that can be attributed to the oil field development work. This paper deals primarily with the initial findings of the first and second phases of the study.

STUDY PROCEDURE

Site-specific observation of oil field traffic provided the basis for the overall analysis. The study procedure is demonstrated in Figure 1, which includes a description of traffic during the development of an oil well, an estimate of the reduction in pavement life under these operating conditions, and an estimate of the increase in cost due to reduced pavement serviceability. These basic considerations are discussed in the remaining sections of this paper and generally follow the conceptual framework of the study procedure.

EVOLUTION OF TRAFFIC AT AN OIL WELL

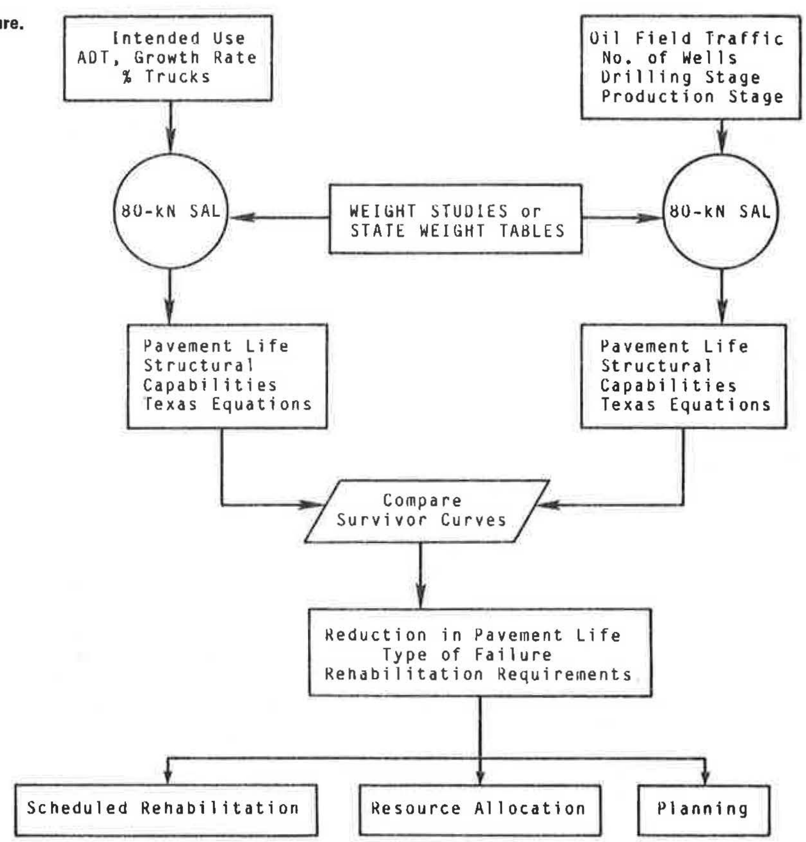
The transportation-related activity that occurs during the evolution of an oil well was established through a process of continuous photographic monitoring. Monitoring also included daily site visits to talk with servicing companies and field representatives. The evolution of an oil well was documented by using traffic counts of vehicles entering and leaving a drilling site. Specific information was obtained by using a Super 8-mm camera to photograph vehicles as they entered or left the site. The camera, actuated by a pneumatic tube, signaled individual frame exposures. This procedure provided a count of the number of axles and an identification of vehicle characteristics. An historical evolution of an oil well site was determined based on conversations held at the site with field representatives and the supplemental photographs taken during the duration of the project.

Five general activities constitute the sequential development of an oil well: site preparation, rigging-up, drilling, completion (rigging-down), and production. In each fundamental stage of oil well activity, unique traffic characteristics developed. Specifically, the vehicle mix included a disproportionate frequency of large vehicles compared with typical operating conditions on many farm-to-market (FM) roads.

Description of Traffic Characteristics

The description of vehicle traffic during the development of an oil well was determined by reviewing the filmed observations. The data collected at three oil well sites were compiled by using a Timelapse 3410 Super 8-mm projector equipped with a remote-control, single-frame adaptor. Because a frame was exposed on each axle application, a valid count of axles was possible and a daily record of vehicle travel was established.

Figure 1. Study procedure.



The vehicles observed entering and leaving the site were classified according to axle combination. Table 1 gives the vehicles defined according to axle combination and corresponding vehicle-type code. The vehicle-type code was used to assign vehicle load weights to the various axle configurations. Coding of the vehicle type generally follows the classification of the American Association of State Highway and Transportation Officials (AASHTO) for axle combinations.

Based on the filmed data and conversations with oil field representatives and the state agencies regulating the production rates, a distribution of truck types was developed. The final results of the well site observations during the construction of the access roads and drilling phases of well development (a 60-day period) are given below:

Truck Type	Trucks No.	Trucks Percent
SU-1	300	22
SU-2	150	11
2-S1 or 2-S2	45	3
3-S2 or 3-S3	655	48
2-1 or 2-2	90	7
3-2 or greater	125	9
Total	1365	100

Further investigation verified an average time period of 60 days for site preparation and drilling. For the oil wells examined in this study, production is assumed to continue for a three-year period per well. Given the allowable production rates (set by the Texas Railroad Commission), truck traffic (3-S2 type) was estimated at 150 trucks/month.

Since a typical FM road must serve both intended-use traffic and the attracted oil well traffic, an estimate of the number of trucks in the intended-use traffic was determined. For the case study discussed in this paper, the following assumptions were selected. These values represent an average traffic condition for typical low-volume FM roads:

Item	Value
Average daily traffic (no. of vehicles)	500
Heavy trucks (%)	5
Annual expected growth rate (%)	5
Traffic split	50/50 in design lane

These assumptions yield 4563 trucks/year in the design lane under the intended-use condition.

Number of 80-kN Single-Axle Load Repetitions

The study procedure required the computation of 80-kN (18-kip) single-axle load (SAL) repetitions to be applied to a pavement section serving both its intended-use traffic and the additional oil field traffic. An estimate of the number of 80-kN SAL repetitions was determined based on TSDHPT loadometer data.

Briefly, the total number of trucks in the intended-use condition was distributed by truck-type classification and assigned an appropriate axle load as reported in the 1980 Texas rural highway weight tables. Each axle load range was converted into 80-kN equivalents by using equivalency factors for flexible pavements.

The vehicles observed entering and leaving an oil well site were categorized by axle combination and were distributed across axle load ranges. To maintain consistency in the analysis, the final distribution was based on TSDHPT axle weight data. This approach prevented biasing the oil truck traffic, since actual axle weights were not possible. The method was considered conservative because it assumed that the axle weight distribution of oil trucks was similar to that of all other truck combinations. Review of the film data and the fact that many oil field vehicles must secure overweight permits further demonstrate the conservative nature of the study. It is suspected that many of the axle loads actually exceed the allowable legal limits.

As indicated in Figure 1, once the intended-use condition and the special-use (oil field) traffic condition are described and equivalent 80-kN SAL repetitions are determined, the structural capabilities of a particular pavement section are calculated. The resulting pavement service life is estimated by using the Texas distress equations developed for bituminous-surface-treated pavements.

DEVELOPMENT OF PAVEMENT ANALYSIS PROCEDURE

The long-term objective of this study is to develop a procedure by which life-cycle costs for thin-surface-treated pavements can be calculated. These life-cycle costs are commonly classified as agency costs and user costs (1). Defining many of these costs is difficult, whereas others do not sufficiently affect the analysis. For the sake of simplicity, the costs considered in this paper are (a) initial capital cost of construction, (b) future capital cost of reconstruction or rehabilitation, (c) maintenance costs, and (d) salvage value. A schematic of the anticipated life-cycle costs is shown in Figure 2.

Table 1. Vehicles defined according to axle combination and corresponding vehicle-type code.

Vehicle Type	Axle Combination	Vehicle Type Code
Single-unit	Passenger car	PC
	2 axles, 4 tires (pickup truck)	PU-1
	2 axles, 6 tires (pickup truck)	PU-2
	2 axles, 6 tires	SU-1
	3 axles	SU-2
Multiunit	2-axle tractor, 1-axle semitrailer	2-S1
	2-axle tractor, 2-axle semitrailer	2-S2
	3-axle tractor, 1-axle semitrailer	3-S1
	3-axle tractor, 2-axle semitrailer	3-S2
	2-axle tractor, 3-axle semitrailer	2-S3
	3-axle tractor, 3-axle semitrailer	3-S3
	2-axle truck, 1-axle balance trailer	2-1
	2-axle truck, 2-axle full trailer	2-2
	2-axle truck, 3-axle full trailer	2-3
	3-axle truck, 2-axle full trailer	3-2
	3-axle truck, 3-axle full trailer	3-3
	3-axle truck, 1-axle balance trailer	3-1
	2-axle tractor, 1-axle semitrailer, 2-axle full trailer	2-S1-2
	3-axle full trailer, 1-axle semitrailer, 2-axle full trailer	3-S1-2

Figure 2. Anticipated life-cycle costs.

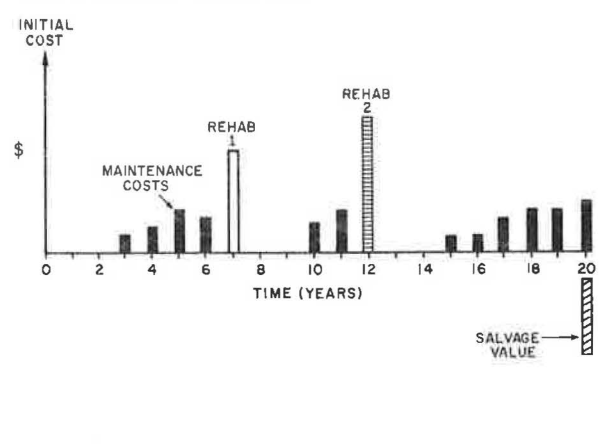
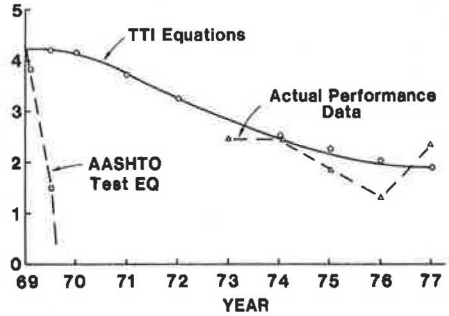


Figure 3. Regression equation versus actual performance.



The pavement shown in Figure 2 received routine maintenance (patching, crack seal, etc.) in years 3 through 6 and received its first rehabilitation treatment in year 7. In Texas, the possible rehabilitation strategies for thin-surface-treated pavements are commonly (a) seal coat, (b) thin overlay, (c) localized reconstruction and seal coat, and (d) full reconstruction, which commonly consists of reworking old base and bringing in 2 or 3 in of new aggregates.

The referenced pavement was predicted to require a seal coat in year 7 and a localized reconstruction in year 12. The salvage value at the end of the analysis period was calculated from the fraction of remaining life of REHAB 2 x the cost of REHAB 2.

A seal coat treatment is most widely used in Texas; many pavements require only regular seal coating at 5- to 9-year intervals. These treatments are applied commonly at the onset of moderate levels of pavement distress (i.e., surface cracking or raveling).

In some instances where the traffic levels have grown significantly, a thin overlay may be warranted. Localized and full reconstruction are applied when the pavement shows a significant amount of load-associated distress [i.e., reduced riding quality or present serviceability index (PSI), rutting, and alligator cracking]. These are frequently found on pavements that have carried heavier-than-anticipated traffic loads or are built on poor subgrades.

In calculating the life-cycle costs (and damage) incurred on thin-surface-treated pavements by special-use traffic, such as oil field traffic, the following must be taken into consideration:

1. The rehabilitation costs under oil field traffic will be incurred earlier in the life of the pavement.
2. Full reconstruction may now be warranted whereas only a seal coat would have been required under the intended-use traffic.
3. Additional maintenance costs will be required.

In order to perform the analysis of life-cycle costs, it is necessary to adopt

1. A method of predicting pavement damage as a function of traffic loading, pavement thickness, subgrade, and environmental conditions (as shown in the following sections of this paper, no adequate method of making these predictions currently exists);
2. A level of damage at which rehabilitation should occur; and
3. A method of identifying the appropriate rehabilitation strategy.

AASHTO Pavement Performance Equation

The AASHTO Road Test conducted in Ottawa, Illinois, in 1960 has been a major source of pavement performance data. Numerous inferences have been drawn from this test, including the Interim Guide equation for the design of flexible and rigid pavement (2). This design equation relates the number of 80-kN SAL repetitions required to reach a predetermined terminal serviceability level for any given pavement structure, climatic condition, and subgrade soil.

A design equation and definition of pavement failure were required in this study to predict the reductions in pavement serviceability attributable to oil field traffic. However, because the AASHTO equation was developed from data collected on flexible pavements with a minimum 2-in thickness of asphalt surfacing, as would be expected, it did not give reasonable predictions of pavement life for the thin-surface-treated pavements under investigation in this study. With a structural number of approximately 1.0-1.5, the AASHTO equation predicts a pavement life for Texas pavement of less than 5000 equivalent 80-kN SALs (see Figure 3). This is considerably less than has been observed on "in-service" thin pavements in Texas.

For these reasons, it was decided to develop new performance equations for thin flexible pavements in Texas.

Texas Flexible Pavement Performance Equations

As the AASHTO Road Test drew to a close, one of the strongest recommendations made by the test staff was that "satellite" studies should be made in other parts of the country in order to determine, with some objectivity, the real effects of subgrade and climate. Texas participated in these studies with the establishment of a flexible pavement data base (3) that contains detailed data on more than 400 sections of pavement. The sections were chosen by a stratified random selection process that gave a reasonably uniform distribution of pavement type, age, materials, layer thickness, soil type, and climate. Of these 400 sections, 132 are on thin-surface-treated pavements on FM-type routes. These thin pavement sections were chosen for analysis in this study. They typically carry between 100 and 750 vehicles/day and were constructed with granular base courses that range in thickness from 4 to 10 in. All of these sections originally had a single or double seal surfacing, and many have received additional seal coat treatments.

Data collection on these sections started in 1972, when the full construction, maintenance, and traffic history of each section was compiled. Riding quality (PSI), distress, and skid surveys have been made periodically on all sections since 1973. In most cases, five or six separate observations have been made on each section since the survey began.

During the distress survey, the following eight types of distress were observed: alligator cracking, transverse cracking, longitudinal cracking, rutting, raveling, flushing (or bleeding), failures (potholes), and patching. Each of these was rated for its area and severity according to the distress identification manual prepared for the State of Texas (4).

In this study, a different form of damage function was assumed that produces a sigmoidal (S-shaped) curve, a shape that appears to reproduce long-term pavement distress and performance better than does the assumed form of the AASHTO Road Test damage function (5, p. 158; 6,7). The assumed form of the damage function for Texas flexible pavements is

$$g = \exp - (\rho/N)^{\beta} \quad (1)$$

where

g = normalized damage,
N = number of 80-kN equivalent SALs, and
ρ and β = constants for each pavement section.

Space does not permit a full description of the analysis undertaken to produce the pavement performance equations used in this study. However, the procedure and typical equations have been published elsewhere (8). An overview of the procedure follows:

1. For each pavement section, an analysis was made of the observed distress and serviceability index histories to determine the values of ρ and β.
2. SAS stepwise regression (9) was then used to perform a regression analysis to explain the variations of ρ and β between sections of the same pavement type. The determined final regression equations are as shown: ρ = f(climate, base thickness, subgrade properties, etc.). An example equation for rutting area is given below:

$$\rho = [-0.1035 + 0.005\,49\,(AVT) + 0.006\,70\,(D) - 0.0015\,(LL) + 0.001\,62\,(PI) + 0.000\,77\,(FTC)] \times 10^6 \quad R^2 = 0.38 \quad (2)$$

where

AVT = average district temperature (°F - 50°F);
D = thickness of flexible base course;
LL = liquid limit of subgrade soil;
PI = plasticity index of suggrade soil; and
FTC = average number of annual air freeze-thaw cycles.

Such equations have been generated for each of the eight distress types and PSI. The correlation coefficients (R^2) of these equations in general range from 0.30 to 0.60. For a few distress types, particularly raveling and flushing, no acceptable models were found. In these instances, the mean values of ρ and/or β were used for predictive purposes.

Like other models for the prediction of pavement distress reported in the literature, the models used in this study generally have low R^2 values. The cause of these low R^2 values is traced to several sources, including the subjectivity of ratings and the unavailability of some important variables. To justify the use of these models, two approaches were taken. First, their predictions of pavement performance were compared with actual performance (Figure 3). The second approach involved asking experienced field engineers to comment on the predictions. Predictions such as those in Figure 4 were shown to a panel of experienced engineers, and they generally concluded that these predictions were reasonable for these types of pavements under the specific loading and environmental conditions.

Comparisons of Equation Predictions with Actual Performance

Several runs were made to test the validity of predicting pavement performance with these regression equations. Such a prediction using the PSI equation is shown in Figure 3. The plot is shown for Texas FM Road 556 in District 19, which is a section in the TTI flexible pavement data base described earlier. This section was reconstructed in 1969, and PSI measurements were made from 1974 through 1977.

As Figure 3 shows, Texas regression equations fit the observed data very well. However, the AASHTO Road Test equation does not do a good job of predicting performance. This pavement had a structural number of approximately 1.0, and the AASHTO equation predicted a life until PSI = 1.5 of 5000 80-kN SALs, which, under the actual traffic levels, would be achieved in the first six months of service.

Pavement Life Predictions

In the AASHTO Road Test, damage was defined in terms of reduction in PSI. In this study, damage was made more general by applying it to distress as well as to a loss of serviceability index. Pavement condition (damage) was expressed in terms of a composite index that combines distress with loss in serviceability to produce a "pavement score". Several states and agencies, including Arizona, Florida, Utah, and the U.S. Air Force, are using such a composite index (10). In general, these indices are used to determine which pavement sections are most in need of rehabilitation, the section with the lowest score being the one most in need of repair.

Texas also uses this pavement score approach (11). A pavement utility score (0-1 range) is calculated by using the following equation and the final pavement score is equal to this utility score x 100.

$$\text{Pavement utility score} = U_{RIDE}^{a_1} \times U_{DIST}^{a_2} \quad (3)$$

where

U_{RIDE} = riding quality utility score of range 0-1,
U_{DIST} = visual distress utility score of range 0-1, and
a_1, a_2 = weighting factors on each utility score.

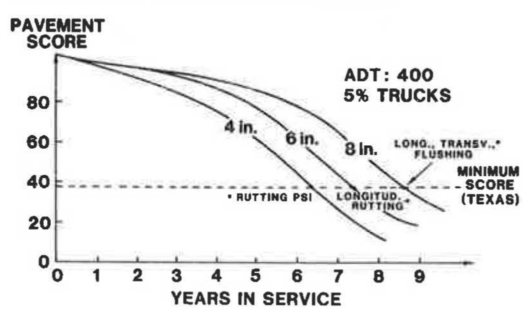
The visual distress utility score is further defined as

$$U_{DIST} = (U_{rut})^{b_1} (U_{ravel})^{b_2} (U_{flush})^{b_3} (U_{failures})^{b_4} (U_{allig})^{b_5} (U_{long})^{b_6} (U_{tran})^{b_7} \quad (4)$$

where each U_i value is determined from the visual inspection data and has a 0-1 range and the b_i are weighting factors.

In using the Texas definition of pavement score, if any single utility value becomes low the pavement utility score will be low. For instance, if the ride value of the highway falls to a critical level, then the pavement score will drop to a failure level. Alternatively, a pavement score may reach failure due to a combination of distress types while still maintaining a high PSI. In Texas, new pavements have a pavement score of 100 and for surface-treated pavements failure level is a pavement score of 35.

Figure 4. Pavement score versus time in service.



The Texas pavement evaluation system (12) uses this pavement score to determine which strategy should be used to rehabilitate pavements that have less than a minimum score. This is done by examining the principal causes of a low pavement score. For surface distresses (e.g., transverse cracking, raveling, and flushing), a seal coat would be recommended. For other load-associated distress types (e.g., severe rutting, alligator cracking, failures of loss of PSI), a sectional or full reconstruction would be recommended.

Predictions of Pavement Score from Pavement Distress Equations

A computer program was written to incorporate the Texas pavement distress equations and pavement score concepts discussed above. The input required to make predictions of pavement performance is as follows:

1. Average daily traffic (ADT);
2. Percentage trucks;
3. Flexible base thickness;
4. Subgrade Atterberg limits (plastic limit and liquid limit), obtained from construction records or county soil reports;
5. Section maximum dynaflect deflection, obtained from a field observation or elastic layered analysis; and
6. Texas county number (for each of the 254 Texas counties the program has stored the relevant climatic data, such as rainfall and average temperatures).

The program uses the input traffic data to calculate the expected 80-kN loading for a preselected analysis period. It then uses the distress equation to predict pavement condition, and hence pavement score, for each subsequent year. When the pavement score reaches the failure level (35), the number of months to failure is calculated. Once failure has occurred, it is then possible to determine which types of distress have caused the reduction in pavement life and consequently which rehabilitation strategy would be most appropriate.

An example of the prediction of variation in pavement score with years in service is shown in Figure 4. The three curves illustrate the predicted change in pavement score for pavements with three different granular base thicknesses. The important points from this figure are as expected: The thinner pavements require rehabilitation much earlier, and the most significant distresses on the 10-cm (4-in) pavements are rutting and loss of PSI. The latter indicates that costly pavement strengthening is required, whereas the 20-cm (8-in) pavement only requires a seal coat.

The work described above has concentrated on the development of a predictive procedure to calculate distress values for any level of 80-kN (18-kip) ESALs. The developed computer program has been extended to permit analysis of what impact oil field development and servicing work will have on pavement performance.

CASE STUDY EXAMPLE

Considerable progress has been made in calculating reductions in pavement life associated with oil-related traffic. The following case study demonstrates the appropriate method and potential of the proposed approach.

Site Conditions

A severely affected oil field area in Burleson County, Texas, was chosen for this case study. Average climatic data taken from the State's computerized weather data files are as follows: Mean annual temperature = 67.4°F, Thornthwaite index = 2.10, and mean annual air freeze-thaw cycles = 35.5. Typical subgrade properties are as follows: Liquid limit = 42 and plasticity index = 23. The range of pavement structural variables (thickness of granular base and Dynaflect maximum deflection) was investigated to represent the range of strong to weak pavements found in Burleson County.

For the purpose of this analysis, the highway was assumed to carry an ADT of 500 vehicles/day, 5 percent of which was trucks. An ADT growth rate of 5 percent/year was assumed.

Traffic Analysis

The first phase of the analysis included a calculation of the intended-use traffic levels (ADT and 80-kN SALs) over an extended 20-year analysis period. Traffic levels were calculated by assuming that the highway under investigation was affected by oil field development traffic after 36 months. In this example, three levels of drilling activity (5, 10, and 20 wells) were investigated. A sample of the traffic level predictions is given in Table 2.

Pavement Performance

The traffic levels presented in Table 2 were used to predict the pavement and distress levels under both the intended-use traffic and intended-use plus oil field traffic.

The relation between predicted PSI and accumulated 80-kN SAL repetitions for the assumed site conditions is shown in Figure 5. Several typical base thicknesses for surface-treated pavements were calculated. The resulting "design curves" generally follow an expected trend of rapid PSI decline on very thin pavements and extended service on thicker bases.

The reduction in PSI caused by the oil field traffic is shown in Figure 6. A thin-surface-treated pavement with a 15-cm (6-in) granular base was subjected to oil field traffic after 36 months in service.

As described earlier, the life of the pavement has been defined in this study in terms of pavement score, which is a composite index that includes both PSI and distress levels. The results of this analysis are shown in Figure 7. The time to failure under each level of oil field loading is given below:

Traffic Level	Time to Failure (months)	Reduction in Life (months)
Intended use + 0 wells	82	0
Intended use + 5 wells	73	9
Intended use + 10 wells	61	21
Intended use + 20 wells	52	30

As would be expected, the increasing oil field traffic drastically reduces the time to failure of these thin pavements. In an oil field area serving 20 wells, the estimated highway life was reduced from 82 to 52 months. When the highway began to feel the impact of oil field traffic in month 36, it still had a perfect score of 100. In slightly more than one year, this score was reduced to the failure level at which the highway will require total reconstruction.

Rehabilitation Costs

A review of PSI levels and distress levels at fail-

Table 2. Cumulative ADT and 80-kN SAL repetitions for intended-use traffic and intended-use plus 10 oil wells traffic (impact starting in month 36).

Pavement Age (months)	Intended Use ADT	Intended Use 80-kN SALs	Intended Use + 10 Wells ADT	Intended Use + 10 Wells 80-kN SALs
1	7 500	376	7 500	376
12	92 091	4 622	92 091	4 622
36	290 648	14 588	335 648	17 298
60	510 040	25 600	945 040	43 584
120	1 164 594	58 452	1 764 593	82 446
240	3 082 621	154 720	3 682 620	178 714

Figure 5. Predicted PSI for various base thicknesses.

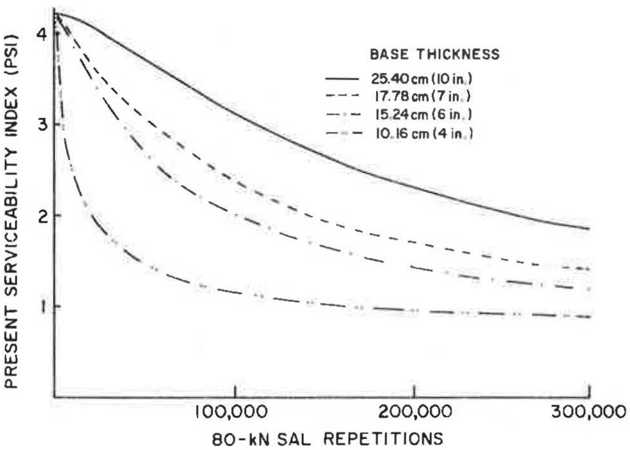
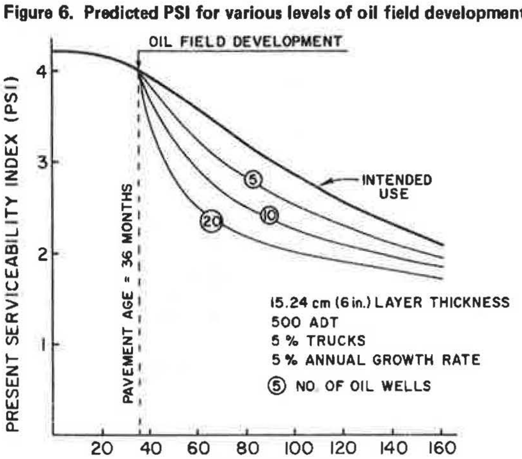


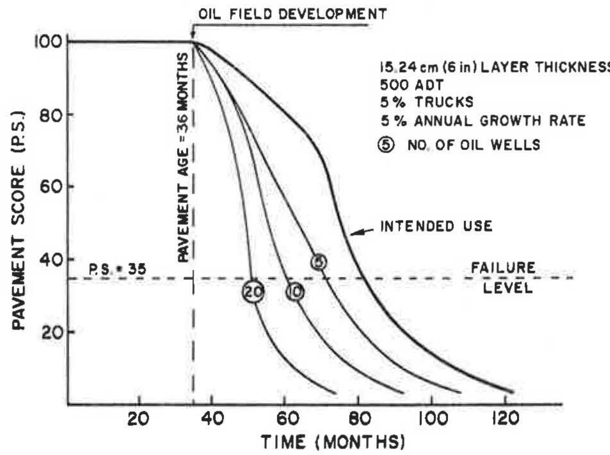
Figure 6. Predicted PSI for various levels of oil field development.



ure indicates that under intended-use traffic the primary causes of the pavement score reaching failure level are surface distress types (such as transverse cracking, raveling, and flushing). However, under the high-intensity heavy traffic generated by the oil fields, load-associated distress (rutting and alligator cracking) becomes the primary cause of pavement failure.

These results are not surprising. It is common to find thin pavements that require regular reseals to prolong their lives; when these pavements carry much heavier than anticipated traffic, rapid pavement deterioration results. When pavement failure occurs under intended-use traffic, a seal coat is

Figure 7. Predicted pavement score for various levels of oil field development.



required to prolong pavement life; with the traffic associated with 20 oil wells, full reconstruction is necessary. Estimated rehabilitation costs, obtained from recent completion plans, are summarized below:

Traffic Level	Time to Failure (months)	Rehabilitation Treatment	Rehabilitation Cost ($/yd²)
Intended use	82	Seal coat	0.50
Intended use plus 20 wells	52	Rework of base + 2 in of base + surface treatment	5.20

Thus, the Highway Department is faced with much higher rehabilitation costs earlier in the life of the pavement. Both the reduced time to failure and increased rehabilitation costs will be inputs to the final life-cycle cost analysis of the future research project.

Impact on Highways of Different Ages

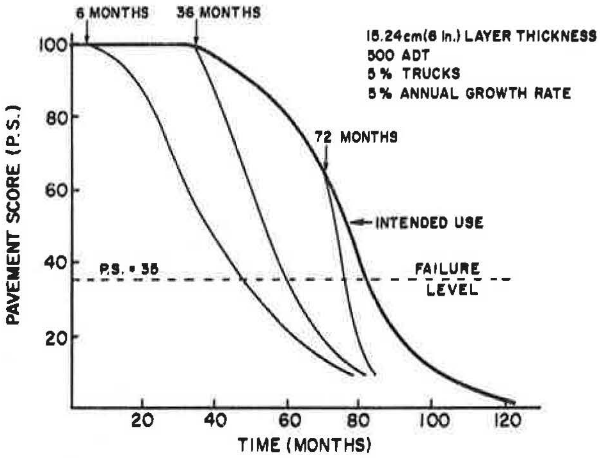
The preceding analysis assumed that the oil field work commenced in month 36. However, it is possible to predict the distress levels on pavements at varying ages. An example of the results of such an analysis is shown in Figure 8, where the impact of oil field traffic (10 wells) on the roadway begins in months 6, 36, and 72, respectively.

A noticeable trend develops when actual loss of service and rate of decline are compared. Although considerable time (service life) is lost on newer pavements, the rate of decline is not as rapid (or severe) as on old pavements. As mentioned earlier, the necessary rehabilitation or remedy is therefore dependent on when the impact occurs and the intensity of the additional traffic concentrations.

CONCLUSIONS

Continuing research is being conducted using the Texas pavement distress equations for bituminous-surface-treated pavements to examine the effects of traffic generated by multiple oil wells. Specific investigations are being performed on roadways with varying ranges of ADT and percentages of trucks in the intended-use condition. These efforts will provide more specific data to assist in the planning, design, and maintenance of existing roadways in the region of oil field development. Anticipating this

Figure 8. Predicted pavement score for different pavement ages.



concentration of unique truck traffic is most beneficial in scheduling resurfacing, restoration, and rehabilitation strategies.

Low-volume roadways carry numerous types of industrial traffic, and each activity shares in the cost of providing an acceptable roadway pavement. The design, or intended use, of a particular pavement assumes that the facility will serve its original intent for some period of time. Although the system can fail due to environmental conditions, it is in serious jeopardy when subjected to traffic conditions well beyond its intended purpose.

Attempts to predict and anticipate needed financial resources and expenditures will aid in the planning and distribution of allocated funds. Although the estimates developed in this study provide site-specific information for assessing the impact of oil field traffic on low-volume, light-duty pavements, the analysis procedure can also be applied to other special-use industrial concentrations.

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The views, interpretations, analysis, and conclusions expressed or implied in this paper are ours and are not necessarily those of TSDHPT.

REFERENCES

1. R. Haas and W.R. Hudson. Pavement Management Systems. McGraw-Hill, New York, 1978.
2. Interim Guide for the Design of Pavement Structures. AASHO, Washington, DC, 1972.
3. J.P. Mahoney and R.L. Lytton. Measurements of Pavement Performance Using Statistical Sampling Techniques. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 207-2, March 1978.
4. J.A. Epps, A.H. Meyer, I.E. Larriemore, and H.L. Jones. Roadway Maintenance Evaluation Users Manual. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 151-2, Sept. 1974.
5. M.G. Sharma, W.J. Kenis, T.D. Larson, and W.L. Gramling. Evaluation of Flexible Pavement Design Methodology Based upon Field Observations at PSU Test Track. Proc., 4th International Conference on Structural Design of Asphalt Pavements, Univ. of Michigan, Ann Arbor, Vol. 1, 1977.
6. M.I. Darter, M.B. Snyder, and R.E. Smith. Development of a Nationwide Concrete Pavement Evaluation System. Univ. of Illinois, Urbana-Champaign, NCHRP Project 1-19, Final Rept., 1980.
7. R.L. Lytton and A. Gracia-Diaz. Evaluation of AASHO Road Test Satellite and Environmental Studies. Texas Transportation Institute, Texas A&M Univ., College Station, NCHRP Project 20-7, Task 17, Final Rept., May 1981.
8. R.L. Lytton, C.H. Michalak, and T. Scullion. The Texas Flexible Pavement Design System. Presented at 5th International Conference on Structural Design of Asphalt Pavements, Amsterdam, Netherlands, Aug. 1982.
9. SAS Users Guide. SAS Institute, Inc., Cary, NC, 1979.
10. Collection and Use of Pavement Condition Data. NCHRP, Synthesis of Highway Practice 76, July 1981.
11. R.L. Lytton and others. Rehabilitation and Maintenance System: State Cost Estimating Program. Texas Transportation Institute, Texas A&M Univ., College Station, Res. Rept. 239-4, 1980.
12. Maintenance Management System: Pavement Evaluation System. Texas State Department of Highways and Public Transportation, Austin, Aug. 1979.