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A Model for Predicting Service Life of Flexible Pavement and Its Impact on Rehabilitation Decisions

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A procedure has been developed to estimate the service life of a flexible pavement based on a combination of predicted ride and distress conditions. These conditions are calculated by using equations developed for Texas, taking into consideration measurable values of material properties, climatic conditions, and design factors. Predicted pavement lives were correlated with actual Texas data and acceptable results were obtained. The most significant contributing distress types that affect the service life were identified by using a discriminant-analysis approach. Discriminant functions were developed for each of the prevalent Texas flexible pavements to determine whether the probability of needing rehabilitation is high for calculated levels of ride and distress. An analysis is provided to assess the cost of a delay in rehabilitation once the predicted life has been reached. In this analysis maintenance, user, and rehabilitation costs are taken into consideration. Rehabilitation costs and strategies dependent on pavement condition are modified from those developed for the California pavement management system.

The development and use of a procedure for estimating the service life of an existing flexible pavement in Texas are described; the estimation of service life is based on predicted values of serviceability and distress. A discriminant-analysis approach is used in the development of the model to define the terminal point for rehabilitation.

The study also includes an analysis for assessing the cost of a delay in rehabilitation once the predicted life has been reached. A present-worth and benefit-cost analysis in which rehabilitation, maintenance, and user costs are considered is used in this assessment.

BACKGROUND

The Texas State Department of Highways and Public Transportation sponsored a project to estimate the remaining service life of a flexible pavement. For the purposes of this paper, service life is defined as the total number of equivalent axle loads or the total number of years that the pavement surface lasts, i.e., time or loads between resurfacings. Similarly, the service life of a surface-treated pavement is taken as the time or loads between seals or surface treatments. Following previous work done on flexible pavements in Texas, pavements are classified as asphaltic concrete, overlay, or surface treated for developing the life-prediction models.

An examination of actual data on flexible pavement performance has suggested the following function to represent the loss in serviceability or percentage of distress:

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

where ρ and β are deterioration-rate constants and N is the number of 18-kip equivalent single axle loads (ESALs). Equations for each of the pavement categories have been developed (1) to estimate the deterioration-rate constants for predicting levels of distress and serviceability based on environmental, material, and design properties. The performance equations predict the affected area or degree of severity for each of the following types of distress: rutting, raveling, flushing, corrugations, alligator cracking, longitudinal cracking, transverse cracking, and patching.

Periodic pavement condition surveys have been performed on selected pavement sections in Texas to monitor the serviceability index and the severity and extent of distress. Distress area and severity are rated as none, slight, moderate, and severe, corresponding to numerical ratings of 0, 1, 2, and 3, respectively. In addition these ratings can be converted into percentages of area or severity; for applications reported in this study, 16.6, 33, and 50 percent correspond to ratings of 1, 2, and 3, respectively. This relationship is used in the development of the service life prediction model to numerically express the extent of each type of distress. Once the extent of distress has been estimated, the service life of a pavement can be determined from Equation 1.

MODEL DEVELOPMENT

Discriminant analysis is a statistical technique in which an observation of unknown origin is assigned to one or more distinct groups based on the value of the observation (2). This technique is used to combine the effects of the different distress and performance types that produce a need for pavement rehabilitation.

Essentially the technique discriminates among groups by using a linear combination of the observations. The coefficients of the linear relation are chosen to maximize the ratio of the difference in the means of the linear combination in each of the two groups to its variance (3). Frequently the distance from each individual observation to each of the group centroids, commonly known as Mahalanobis' D^2-statistic (4), is used as the criterion for classification purposes. This smallest distance dictates the assignment rule and may be stated as follows:

$$D_j^2(x) = (x - \bar{x}_j)^T S_j^{-1} (x - \bar{x}_j) + \ln|S_j| - 2\ln(r_j) \qquad (2)$$

where

$D_j^2(x)$ = generalized squared distance from observation x to group j,
x = vector of variables in an individual observation,
$\bar{x}_j$ = vector of means of variables in group j,
S_j^{-1} = inverse of covariance matrix for group j,
$|S_j|$ = determinant of covariance matrix for group j, and
r_j = prior probability of assignment to group j (proportion of observations in group j to total number of observations in all groups).

When the covariance matrices are equal, the quadratic terms cancel because of symmetry and linear equations result for the distance measure. The variables used in this study are the serviceability index and the area and severity of distress, which are shown by using values of 0, 1, 2, or 3. To obtain the observations for the analysis, a sample of sections was used for which condition survey information was available for the years 1973-1978 for each of the pavement types. The observations were classified into two groups: those that had been resurfaced during the 1973-1978 period and those that had not. Results from the 1977 condition survey or those of the years preceding a decision to rehabilitate (resurface) were used to describe each section.

Discriminant analysis was used to determine which of the types of distress or serviceability index were the best indicators of a decision to resurface and how they were weighted relative to one another. The decision to resurface in terms of discriminant analysis is a decision to assign a particular section of pavement to the group of pavements that need resurfacing.

In order to obtain an effective assignment rule--that is, one with a low error rate--the variables must provide information about the two populations, which enables assignments to be made. The complexity of the discriminant function may be reduced because the set of variables used is limited to those that contribute the most to the assignment of the observations into the two groups. A regression analogy, credited to Cramer (5) and applicable to discriminant analysis with two groups, allows the problem to be treated as a multiple regression with the creation of a dummy variable as indicator of group membership. To accomplish this, a new variable (y_i) is defined by one of the following equations:

$$y_1 = n_2/(n_1 + n_2) \quad \text{if } x_i \text{ is a member of group 1} \qquad (3)$$

$$y_2 = n_1/(n_1 + n_2) \quad \text{if } x_i \text{ is a member of group 2} \qquad (4)$$

where

y_i = dependent variable for observation i,
n_1 = number of observations in group 1, and
n_2 = number of observations in group 2.

This substitute variable made it possible to examine all of the linear regression relations among the dependent and independent variables. The model with the smallest mean-square error was chosen to provide the set of variables (distress types or serviceability index) that are used in the discriminant function. An alternative approach to this one could have used a forward or backward stepwise regression model, available in many standard computer software packages. However, the procedure used here was believed to be superior to the stepwise procedure because the order that the variables enter into the model does not affect the final set of variables.

Table 1 gives the distress types that proved to be the best indicators of the need to resurface each of the three pavement types. The number of variables used in the model is greatly reduced for each of the pavement types. Interestingly, the pavement serviceability index (PSI) was chosen only for the overlaid pavements. This corresponds to the widely held opinion in Texas that pavements are rehabilitated mainly because of existing distress rather than the quality of the ride. The set of variables for each pavement type includes at least some of the most important distress types causing serious surface deterioration, such as alligator cracking and longitudinal and transverse cracking.

By using the variables listed in Table 1, discriminant functions are developed to identify pavement sections in need of resurfacing. Hypothesis testing of the covariance matrices of the two groups (resurfaced and not resurfaced) revealed that they are not statistically equal, resulting in quadratic discriminant functions, which are more appropriately handled by a computer program. The classification performance of the models is found to be acceptable by examining the number of correct assignments made with the test data. The results of this analysis are displayed in Table 2.

Linear approximations of the discriminant functions for each pavement type are given in Table 3. However, an examination of the number of correct predictions made by the linear functions, given in Table 4, shows the superiority of the quadratic functions in identifying sections that belong to the group of resurfaced pavements.

It may be noted that a limited number of observations existed for resurfacing in the asphalt-concrete and overlay categories. The resulting functions may be somewhat biased because of this. However, the results given in Table 2 demonstrate that the models are fairly good discriminators.

Table 1. Serviceability and distress types selected for discriminant analysis.

Pavement Type	Serviceability or Distress Type
Asphalt concrete	Alligator-cracking severity
	Longitudinal-cracking severity
	Longitudinal-cracking area
	Transverse-cracking severity
Overlay	Pavement serviceability index (PSI)
	Alligator-cracking area
	Longitudinal-cracking severity
	Longitudinal-cracking area
Surface treated	Rutting severity
	Rutting area
	Longitudinal-cracking severity
	Transverse-cracking area
	Patching area

Table 2. Number of observations correctly predicted by quadratic discriminant functions for three types of pavement.

Pavement Type	Group	No. of Cases	Correct Predictions No.	Correct Predictions Percent
Asphalt concrete	Resurfaced	5	4	80.0
	Not resurfaced	76	71	93.4
Total		81	75	92.6
Overlay	Resurfaced	16	10	62.5
	Not resurfaced	66	60	90.0
Total		82	70	85.4
Surface treated	Resurfaced	56	39	69.6
	Not resurfaced	77	62	80.5
Total		133	101	75.9

Table 4. Number of observations correctly predicted by linear discriminant functions for three types of pavement.

Pavement Type	Group	No. of Cases	Correct Predictions No.	Correct Predictions Percent
Asphalt concrete	Resurfaced	5	3	60.0
	Not resurfaced	76	73	96.1
Total		81	76	93.9
Overlay	Resurfaced	16	8	50.00
	Not resurfaced	66	61	92.42
Total		82	69	84.1
Surface treated	Resurfaced	56	29	51.8
	Not resurfaced	77	64	83.1
Total		133	93	69.9

Table 3. Linearized discriminant functions for three types of pavement.

Pavement Type	Variable	Group Resurfaced	Group Not Resurfaced
Asphalt concrete	Constant	-8.1085	-0.5903
	Alligator-cracking severity	1.8279	0.4700
	Longitudinal-cracking severity	-4.6091	0.3768
	Longitudinal-cracking area	5.6596	0.3020
	Transverse-cracking severity	2.4684	0.3330
Overlay	Constant	-13.7967	-13.0364
	PSI	5.8827	6.6062
	Alligator-cracking area	2.0832	1.3395
	Longitudinal-cracking severity	-1.3448	0.6792
	Longitudinal-cracking area	3.4315	0.1462
Surface treated	Constant	-5.9554	-4.7224
	Rutting severity	3.2586	2.4665
	Rutting area	2.3691	3.0307
	Longitudinal-cracking area	1.4207	1.0717
	Transverse-cracking area	1.2046	0.4998
	Patching area	0.9275	0.4040

DESCRIPTION OF LIFE-PREDICTION MODEL

The serviceability and distress performance equations are used with the discriminant functions to predict the life of a section of pavement. As aging occurs or loads accumulate, signs of distress become evident and the serviceability index may decrease. At the point where the equations predict a change in the condition rating, the overall rating for each of the corresponding distress and serviceability variables is evaluated by the corresponding discriminant function. This process continues until the probability of being assigned to the group of pavements in need of resurfacing reaches or exceeds a specified value. Because the goal of the model is to determine when a pavement is in need of rehabilitation, which may be considered a critical decision, a relatively high assignment probability is warranted. The probabilities used in the model are 0.70, 0.70, and 0.80 for asphalt-concrete, overlaid, and surface-treated pavements, respectively. The probability for assigning an observation to a group was described by Eisenbeis and Avery (4) as follows:

$$P[j/x] = \exp[-0.5\, D_j^2(x)] / \sum_K \exp[-0.5\, D_K^2(x)] \quad (5)$$

In Equation 5, P[j/x] is the posterior probability that observation x belongs to group j.

The translation of pavement life from 18-kip ESALs into time is accomplished by using annual average daily traffic (AADT), estimated traffic growth, percentage of trucks, and truck traffic information from 1980 W-4 and W-5 tables with the AASHTO procedures (6). Assuming a linear traffic growth rate, the following expression relates time to the accumulated load:

$$A = N_0\, [I + 0.5\,(G)\, I\,(I - 1)] \quad (6)$$

where

N_0 = yearly 18-kip equivalent at time 0,
I = number of years,
G = annual growth rate, and
A = accumulated 18-kip ESALs.

Results produced from the life-prediction model were correlated with actual data from Texas pavements. The statistical findings from regression and correlation analyses are shown in Figures 1, 2, and 3.

The resulting regression lines are close to the desired zero intercept with a slope of 1 (a 45-degree line on the graphs). With correlation coefficients in the range of 0.5 to 0.6, about 26 to 37 percent of the variation in the actual service life is accounted for by the linear relationship. However, an examination of the F-values (9.9 to 14.6) reveals that a significant amount of the variation in the response variable (actual life) is accounted for by the linear model. Although these results may not be extremely impressive, they are promising, especially because there are many variables in the decision process for determining when a pavement should be resurfaced, including the availability of funding, which may or may not be related to the need for resurfacing.

COST ANALYSIS

Two basic functions are accomplished by the cost analysis to be described: assessment of the cost of delaying the predicted rehabilitation by using a present-worth analysis and provision of a benefit-cost ratio to help justify the proposed rehabilitation. The analysis includes rehabilitation and maintenance costs and benefits due to savings in fuel consumption, travel time, and reduced maintenance.

Rehabilitation costs are dependent on the strategies used, which are dictated by the principal cause of the resurfacing. The strategies used in this model are customized versions of those suggested by the California pavement management system (7) and appear in Table 5. As part of the customizing, the alternatives have been stated in terms of the scores obtained from the condition survey. The alternative

Figure 1. Actual versus predicted performance for asphalt-concrete pavements.

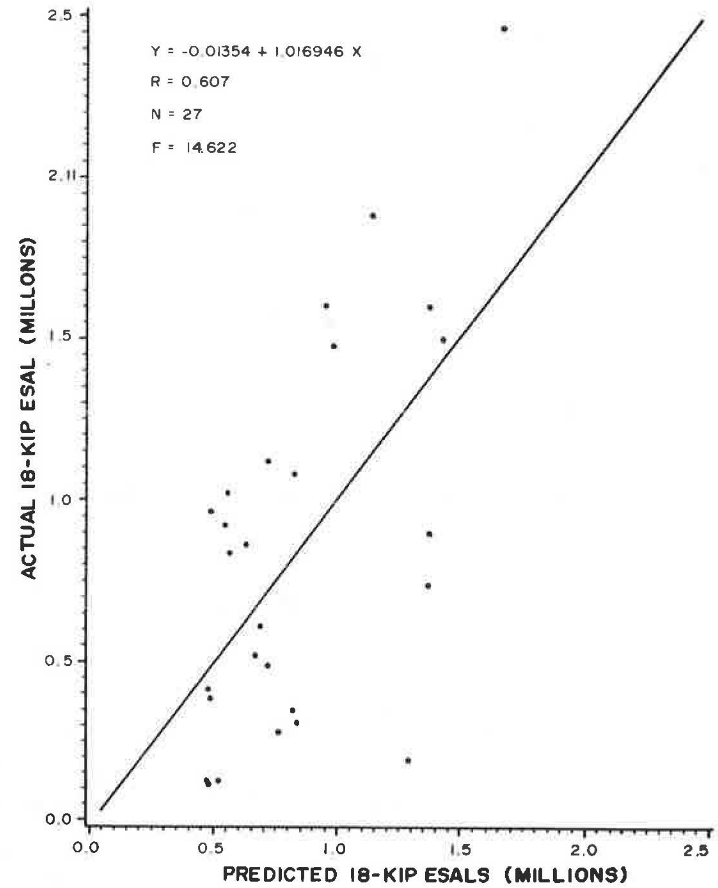


Figure 2. Actual versus predicted performance for overlaid flexible pavements.

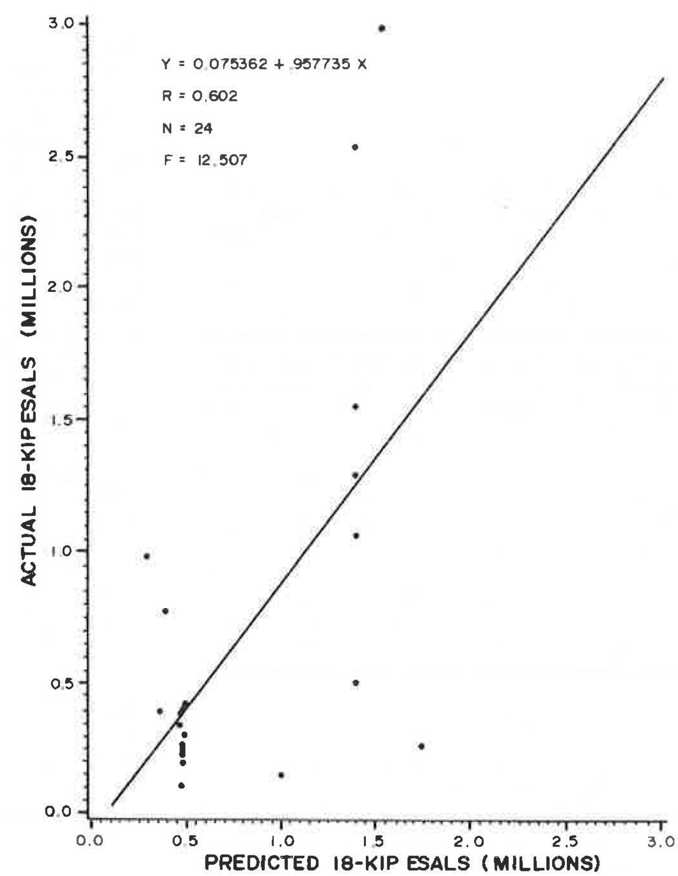


Figure 3. Actual versus predicted performance for farm-to-market surface-treated pavements.

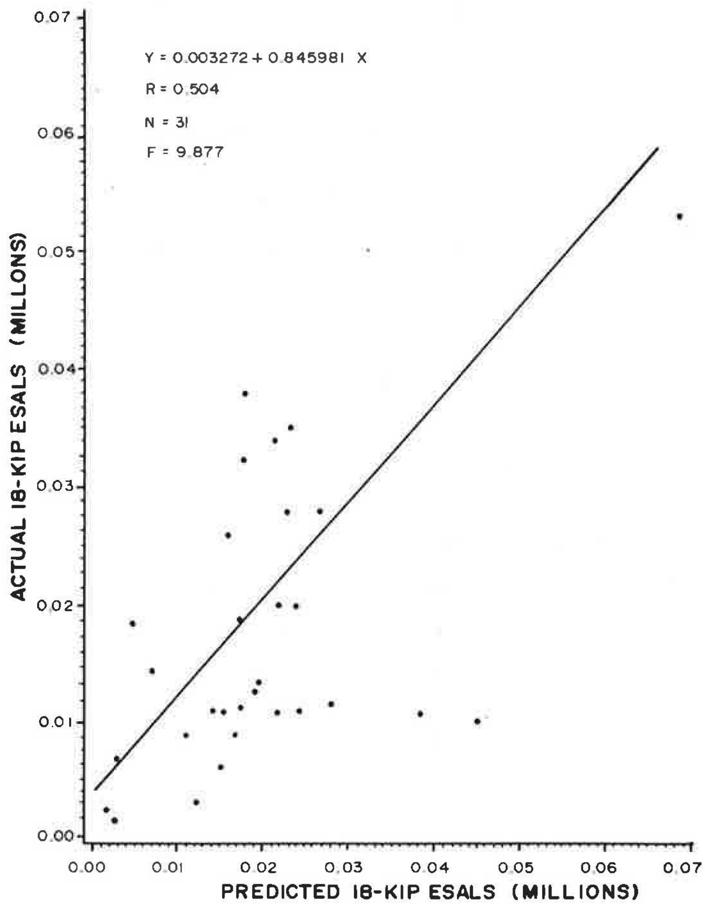


Table 5. Rehabilitation strategies for three types of pavement.

Pavement Type	Cause	Strategy by Condition: Slight	Moderate	Severe
Asphalt concrete	Alligator cracking	Fill cracks	1-in. overlay and local dig-out	5.0-in. overlay
	Longitudinal and transverse cracking	Do nothing	Fill cracks	Rubberized asphalt chip seal
Overlay	Alligator cracking	Fill cracks	1-in. overlay and local dig-out	5.0-in. overlay
	Longitudinal cracking	Do nothing	Fill cracks	Rubberized asphalt chip seal
	PSI < 2.9	Leveling and 1-in. overlay	Leveling and 1-in. overlay	Leveling and 1-in. overlay
Surface treated	Rutting	Seal coat	Double seal coat	Sectional reconstruction
	Longitudinal and transverse cracking	Do nothing	Do nothing	Fill cracks
	Patching	Do nothing	Seal coat	Double seal coat

is matched to the predicted condition for each applicable distress and serviceability type, and the most costly strategy is chosen to be the cost of rehabilitation.

Pavement maintenance costs are assumed to increase with pavement age. For lack of a more precise model developed for Texas, the EAROMAR (8) equations were used, even though they were developed to predict maintenance workloads for multilane freeways. The model is as follows:

$$C_t = (1{,}100C_1 + 1{,}000C_2 + 5C_3)/\{1 + \exp[(t - 10)/1.16]\} \quad (7)$$

where

C_t = annual maintenance cost (yr/lane mile),
C_1 = bituminous skin patching (\$3.47/yd²),
C_2 = crack sealing (\$0.25/linear ft), and
C_3 = bituminous base and surface repair (\$450/yd³).

For highway types other than freeways, the EAROMAR results are appropriately modified by multiplying them by a reduction coefficient reflecting past maintenance data for Texas. The results of a comparison of maintenance costs for farm-to-market and U.S. and state highways with those for Interstate routes in Texas (9) is as follows. (As an illustration, the maintenance cost on farm-to-market roads is 38.2 percent of the cost per lane mile computed by the EAROMAR equations.)

Highway System	No. of Observations	Avg Maintenance Cost per Lane Mile ($)	Percentage of Interstate Cost
Interstate	4	1,028.00	
Farm to market	23	391.00	38.2
U.S. and state	62	325.00	31.6

The present-worth analysis focuses on the rehabilitation strategy and on the annual maintenance during the analysis period, which corresponds to the service life of the rehabilitation strategy, which in turn is determined by the service-life prediction model. Costs of delaying rehabilitation beyond the predicted end of a pavement's life are calculated for delay periods from 1 to 5 years. In order to compare the alternatives over equal time spans, the unused value of the rehabilitated pavement is taken into consideration. The present worth of delaying rehabilitation may be expressed as follows:

$$PW = \sum_{n=1}^{r} [C_n \cdot (P/F_{i,n})] + \left\{ R_c \cdot (A/P_{i,m}) + \sum_{n=1}^{m} [C_n \cdot (P/F_{i,n}) \cdot (A/P_{i,m})] \right\} [(P/A_{i,m-r}) \cdot (P/F_{i,r})] \quad (8)$$

where

i = interest rate,
R_c = rehabilitation cost,
m = analysis period,
r = year in which rehabilitation occurs,
C_n = maintenance cost in year n,
$A/P_{i,m}$ = equal-payment-series capital recovery factor = $i(1 + i)^m/[(1 + i)^m - 1]$,
$P/A_{i,n}$ = equal-payment-series present-worth factor = $1/(A/P_{i,m})$,
$P/F_{i,n}$ = single-payment present-worth factor = $1/(1 + i)^n$.

The unused value may be expressed as follows:

$$U = R_c \cdot (A/P_{i,m}) \cdot (P/A_{i,r}) \quad (9)$$

BENEFIT-COST ANALYSIS

In this section, a model is constructed to evaluate the benefits resulting from reductions in user and maintenance costs due to increased serviceability. The resulting benefit-cost analysis is useful in relating the probability of a proposed alternative to its cost. Two types of user costs are considered, fuel consumption and travel time, because these represent disbursements on the part of the user in contrast to more subjective abstract costs, such as those for discomfort. In addition, accident costs and vehicle operating costs, often considered in an analysis of this type, were not included for lack of an adequate model to relate them to serviceability or the distress types mentioned previously. Fuel consumption costs and travel time costs were estimated for different levels of the serviceability index as predicted by the corresponding performance equation. To calculate the benefits derived from increasing the serviceability, a concept illustrated in Figure 4 is used (10). The underlying assumption is that costs increase with pavement age up to a point, and resurfacing (point G) updates the age and returns the cost structure to zero. The benefits would be the difference between the cost under the assumption that no improvements were made and the cost under the assumption that an improvement takes place. This benefit is represented by the region BDEG in Figure 4 for a time span of N years.

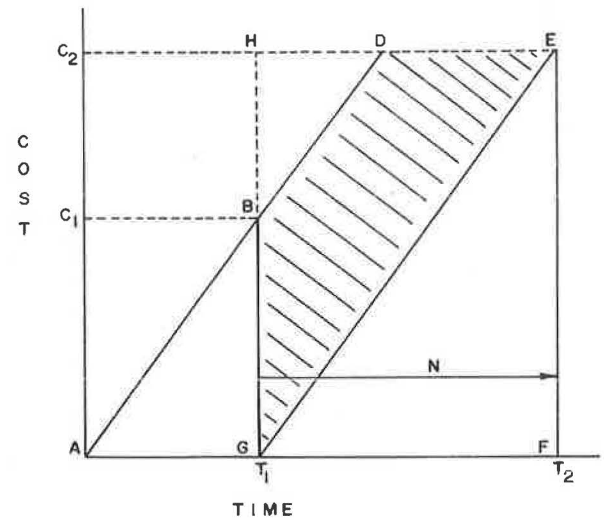
With this concept the following equation was developed to calculate the benefits derived from fuel savings:

$$B_f = \{[(F_2 N)/2] - [(F_2 - F_1)/2]\ [N - N(F_1/F_2)]\} \times [(AADT)(L_s)(365)(1/12)(CG)(P/A_{i,n})]/N \quad (10)$$

where

B_f = present worth of benefits from fuel savings due to resurfacing,

Figure 4. Concept of time versus cost (10).



F_2 = maximum percentage of reduction in fuel costs (1.5 percent) due to resurfacing,
F_1 = percentage of reduction in fuel costs based on PSI before resurfacing,
N = service life,
CG = cost of a gallon of gasoline, and
L_s = length of section.

The percentage of reduction in fuel use as shown by Ross (11) is given by the following:

$$F_1 = 0.0001879 \cdot (PSI_A - PSI_B)/[0.043771 - (0.0001879 \cdot PSI_A)] \quad (11)$$

where PSI_A is the serviceability index after resurfacing and PSI_B is the serviceability index before resurfacing.

It should be noted that this equation yields results considerably different from those interpolated from Claffey's work (12); the maximum difference is about 30 percent. To illustrate the magnitude of benefits per mile derived from fuel savings, an AADT of 1,000 vehicles may be assumed together with a service life of 8 years, an annual interest rate of 10 percent, and a PSI before resurfacing of 2.5. The present worth of benefits due to fuel savings for this example would be calculated as follows:

$$F_1 = 0.0001879 \cdot (4.7 - 2.5)/[0.043771 - (0.0001879)(4.7)] = 0.0096 \quad (12)$$

$$B_f = \left([(0.015)(8)/2] - [(0.015 - 0.0096)/2] \{8 - [8(0.0096) \div 0.015]\}\right) \{[(1{,}000)(365)(1.20)(5.3349)]/[(12)(8)]\} = \$1{,}271.00 \quad (13)$$

For time savings, the equation used for calculating benefits is as follows:

$$B_t = (T_a - T_b)\ AADT \cdot V \cdot (P/A_{i,n}) \quad (14)$$

where

B_t = present worth of benefits from time savings due to resurfacing,
T_b = travel time before resurfacing,
T_a = travel time after resurfacing, and
V = value of time per hour.

Speed increases due to resurfacing are as follows (10,13):

Speed Limit (mph)	Increases (mph) by PSI 2.6-2.11	2.1-1.81	1.8-0
25-30	0	0	2
35-40	0	2	4
45-50	2	4	6
55	4	6	8

As an illustration, for the previously stated example and a speed limit of 55 mph with a $6.00 delay cost per hour, the benefits due to time savings would be calculated as follows:

$$B_t = [(1/51) - (1/55)]\ (1{,}000)\ (6)\ (5.3349) = \$16{,}661.00 \qquad (15)$$

Benefits derived from reduced maintenance costs (B_m) are estimated by calculating the present worth of the difference between maintenance costs when there is no resurfacing and those when resurfacing takes place. Because maintenance costs are calculated as a function of pavement age, resurfacing updates the age of the pavement and thus reduces costs.

As an illustration, a two-lane state highway may be assumed with a 10-year-old pavement at the time of rehabilitation. It is further assumed that the new surface lasts 8 years. Savings in maintenance costs would be calculated as follows:

$$B_m = 2[1{,}100\,(3.47) + 1{,}000\,(0.25) + 5(450)] \times \left(\sum_{i=1}^{8} [1/1 + \exp(-i/1.16)] - \{1/1 + \exp[-(i-10)/1.16]\}\right) = \$18{,}821.00 \qquad (16)$$

The total benefits for fuel savings, time savings, and reduced maintenance for this example are $36,753.00/mile.

Costs for the benefit/cost (B/C) ratio are those of the rehabilitation strategy discussed previously, which yields the following relationship:

$$B/C\ \text{ratio} = (B_f + B_t + B_m)/R_c \qquad (17)$$

Assuming in the example that the principal cause of rehabilitation is a moderate level of alligator cracking, the cost of rehabilitation as modified from the California method is given by the following:

$$R_c = [L_s\,(N + 0.67) \cdot CJ + (L_s)\,(N)\,(0.05)\,(CE)] \cdot 1.2 \qquad (18)$$

where

L_s = length of project (1 mile),
N = number of lanes (two),
CJ = cost of 1-in. overlay per lane mile ($10,000.00), and
CE = cost of base repair and patching per lane mile ($140,000.00).

The resulting rehabilitation cost is $56,000.00 with a B/C ratio of 0.64. Delaying this project until a more costly rehabilitation strategy must be taken may result in a lower B/C ratio. However, if the same strategy applies, benefits will increase and the ratio will increase; this makes the project more competitive with other projects.

The negligible savings in fuel contributes to making this project unfavorable in the light of a benefit-cost analysis. Previous studies (10) and studies in other countries (14) suggest a stronger influence (larger benefits) of savings in fuel in the determination of total benefits.

SUMMARY

A model has been described that is capable of predicting the service life of a flexible pavement section and of evaluating the effects of a prompt or delayed decision in taking rehabilitation actions. The model combines discriminant analysis, a statistical technique, with performance equations developed for Texas conditions and produces results that compare favorably with actual data collected on sections of the state's highway system.

A framework is provided to perform present-worth analysis based on maintenance and rehabilitation costs. The period for this analysis is assumed to be the life of the surfacing, which in turn is predicted by the life-prediction model, and the rehabilitation strategies are also generated internally. A benefit-cost analysis is provided to supplement the present-worth analysis. This model is expected to aid the state in planning or programming future expenditures on pavement rehabilitation projects.

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Notice: The opinions expressed in this paper are those of the authors and not necessarily those of the Texas State Department of Highways and Public Transportation.

Abridgment

Field Investigation of Resource Requirements for State Highway Routine Maintenance Activities

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The first phase of a comprehensive study to identify potential cost and energy savings in routine maintenance activities on the state highway system in Indiana is described. In this phase the current highway routine maintenance standards of the Indiana Department of Highways were reviewed and updated based on data collected in the field, and guidelines for estimating equipment fuel consumption were established. The needs for different resources (materials, labor, and equipment) used in various routine maintenance activities (types, rates of consumption, and frequencies of use) were identified. Energy consumed in each activity was determined as the number of gallons of fuel required to produce one production unit of an activity. The preliminary data analysis indicated that there is a potential for considerable cost and energy savings through better assignment of equipment in different activities. The information developed in this phase can be used directly by the Indiana Department of Highways in preparing their annual maintenance program.

Inflation and price increases have significantly affected the routine maintenance expenditures for the state highway system in Indiana. For example, the total expenditure on routine maintenance activities in 1976 was $47 million, whereas in 1981 the expenditure increased to about $70 million (1,2).

The recent increase in price for all petroleum-related materials includes such derivatives as motor fuel, asphalts, and tars. Motor fuel is the material with the greatest price increase, and it is critical to any maintenance activity because of the dependence of the equipment fleet on it. For instance, the maintenance equipment fleet of the Indiana Department of Highways (IDOH) consumed about $2.6 million worth of motor fuel in 1976, and in 1981 this increased to about $6.0 million. In addition the portion of total material costs assigned to motor fuel has increased with time; for example, 18 percent of the total material costs was assigned to motor fuel in 1976 as opposed to 28 percent in 1981.

From the foregoing observations it is evident that motor fuel must be considered a special resource that needs to be controlled. This can be achieved only through detailed information on equipment use and associated fuel consumption. Many studies have been initiated in the past on the general topic of energy use by maintenance equipment (3-10). However, the information available does not provide either the degree of variability of fuel consumption among different equipment types or the variability of fuel consumption by the same equipment type when used in different maintenance activities. Furthermore, the current standards of equipment use by IDOH are measured by the number of hours or miles for which a piece of equipment is used. These measures cannot provide useful information about fuel consumption unless other supporting rates are developed. Such rates as miles per gallon and gallons per hour are useful in recognizing the amount of fuel consumed as well as the degree of use of a piece of equipment.

The objective of the study reported in this paper is to update the current standards of maintenance resource needs and to establish new standards for fuel consumption by maintenance equipment. This information can then be used in efforts to achieve maintenance cost and energy savings. The study was sponsored by the Federal Highway Administration and IDOH and the results obtained will be of use to IDOH in programming routine maintenance activities.

STUDY METHODOLOGY AND DATA-COLLECTION PROCEDURE

The existing system of maintenance data recording was used with some modifications. The current reporting system of IDOH consists of filing work records on a crew day card. Information recorded on such cards includes activity type, location, date, number of crew members and corresponding man hours, equipment used and corresponding miles or hours, materials used and corresponding quantities, and total accomplishment (production units).

For 6 weeks during October through November 1981, data were collected from selected subdistricts representing the six districts of IDOH. This period was considered unique in that most maintenance activities were performed during this time. Nevertheless, some activities could not be included: activities that are not applied at that time of the year (for example, snow and ice removal); activities with low occurrence, such as seal coating; and activities of administrative nature, such as training, stand-by time, and so on.

The current data-recording system by using crew day cards does not include any information about the amount of fuel consumed by different equipment types. Consequently the subdistrict managers were instructed to fill each piece of equipment with fuel before and after each job. The difference was then to be recorded on the same crew day card with other associated activity data.

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