Effects of Routine Maintenance Expenditure Level on Pavement Service Life

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This research was undertaken to determine how the level of routine maintenance expenditure affects pavement surface condition and pavement service life. The relationship between pavement roughness and pavement age was examined under different levels of routine maintenance expenditure. Surface roughness was used as a measure of pavement surface condition, and pavement age at terminal roughness value was considered as a measure of pavement service life. The effects of traffic loading and regional factors were included in this relationship. Data on a selected number of pavement sections from the Indiana state highway system were used to develop appropriate prediction models. The results of these models indicated that, if patching and crack-sealing expenditure increases from low to high levels, resurfacing can be postponed 1 to 3.3 yr for overlaid pavements and 1.6 to 8 yr for flexible pavements.

Resurfacing a highway section usually causes an immediate reduction in the need for pavement routine maintenance (*1*). However, past research has not revealed how long resurfacing can be postponed if appropriate levels of pavement surface maintenance are undertaken. This research effort studied the effects of routine maintenance expenditure level on pavement surface condition and resurfacing need. A relationship between pavement roughness as a measure of pavement surface condition and pavement age as a measure of pavement service life was introduced under different levels of routine maintenance expenditure. This relationship was used to relate pavement resurfacing needs to the level of routine maintenance. An assumption was made that improvements in pavement condition are positively related to the level of routine maintenance expenditure.

BASIS OF THE APPROACH

Pavement performance is a result of the combined effects of traffic load, environment, age, initial design and construction, and past maintenance. The most widely used aggregate pavement performance model is the relationship between axle loading and pavement deterioration developed through the AASHO Road Test (*2*). An approach proposed by Fwa and Sinha (*3*), which was based on the serviceability performance concepts developed by the AASHO Road Test, measures pavement performance in terms of Present Serviceability Index–Equivalent Single-Axle Load (PSI–ESAL) loss. In the research documented in this paper, the following initial assumptions were made:

- Pavement roughness can be used instead of PSI as a direct quantitative measure of pavement performance. This assumption is derived from the conclusion of several studies (*4,5*) that the use of roughness measurements is often sufficient for predicting the serviceability index. Roughness data are readily available to most highway agencies. Also, the general public perceives pavement roughness as more critical than structural adequacy in determining the timing for pavement improvement (*6*).
- Pavement age, as measured from the most recent reconstruction or resurfacing, can be used to represent the combined effects of traffic and environment for a small range of traffic volume as well as for a small variation in climatic conditions. Since pavement age alone can account for about 80 percent of the variations in damage responsibilities (*3*), this assumption is reasonably valid. Consequently, pavement age at terminal roughness value can be used as a measure of pavement service life.
- Pavement type and highway class represent initial design and construction.

CONCEPTUAL RELATIONSHIP BETWEEN PAVEMENT ROUGHNESS AND PAVEMENT AGE

To predict the effect of routine maintenance expenditure level on pavement service life, pavement performance must be considered over time under different levels of routine maintenance. Since routine maintenance expenditure level can be expected to represent both the quality and quantity of maintenance work, it can be used as a measure of the level of routine maintenance performed on a given pavement. On the basis of this assumption and the pavement performance and maintenance relationship developed by Fwa and Sinha (*3*), pavement roughness can be related to different expenditure levels of routine maintenance (L_i) as shown in Figure 1. Figure 2 shows pavement performance over time under three different maintenance levels. Pavement service life (n) under zero-maintenance can be determined on the assumption that, when pavement roughness reaches a terminal value (RN_T), the pavement needs to be resurfaced or reconstructed. Resur-

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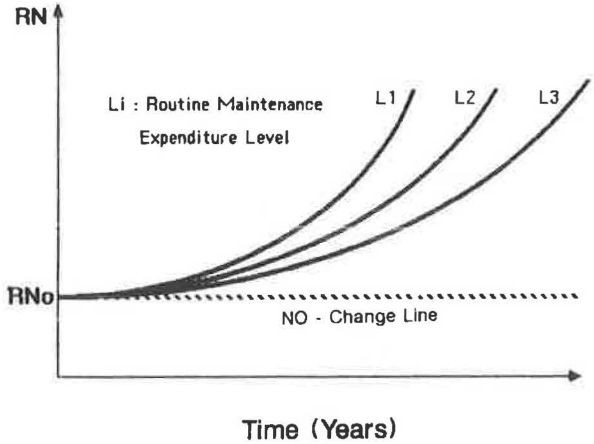
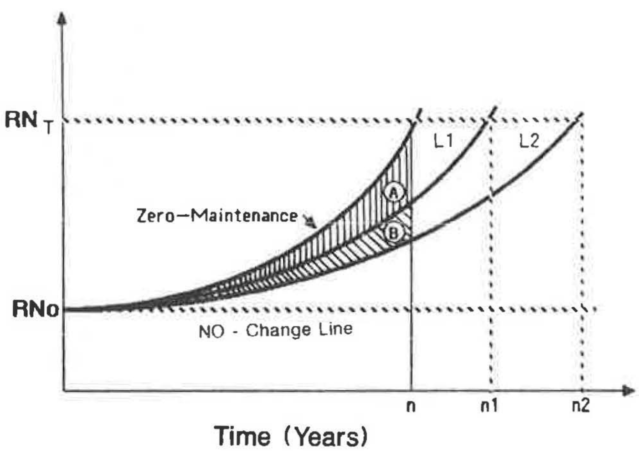


FIGURE 1 Pavement roughness curves for different levels of routine maintenance expenditure.



LEGEND

Li Routine Maintenance Expenditure Level

Area `A` Represents the Improvement in Pavement Surface Condition if Maintenance Expenditure Level, L1 is applied.

Area `B` Represents the Improvement in Pavement Surface Condition if Maintenance Expenditure Level, Increases from L1 to L2

RN_T Terminal Roughness Value at which Resurfacing is Required

FIGURE 2 Effects of routine maintenance expenditure levels on pavement service life.

facing is defined in this research as the placement of additional surface material over an existing pavement to improve serviceability or to provide additional strength. It is considered a first level of improvement (one that significantly affects serviceability) as opposed to higher levels of improvement such as restoration or rehabilitation (requiring improvement of structural support) and reconstruction (where an old pavement structure is removed and replaced).

RN_T is equivalent to 2.0 or 2.5 PSI, depending on pavements type and highway class. Area A in Figure 2 represents the improvement in pavement surface condition over time (n) if expenditure level L_1 is applied instead of zero-maintenance. Area A is also equivalent to the reduction in deterioration of pavement surface condition if L_1 is applied. Area B represents the improvement in pavement surface condition over time (n) if the expenditure level is increased from L_1 to L_2. The n_1 and n_2 represent pavement age at terminal pavement roughness (RN_T) for expenditure levels L_1 and L_2, respectively, and $(n_1 - n)$ is the increment in pavement service life due to the routine maintenance expenditure at level L_1. For expenditure level L_2, pavement service life increases by $(n_2 - n)$.

IDENTIFICATION OF TRAFFIC AND MAINTENANCE EXPENDITURE LEVELS

A data base was developed for pavement routine maintenance, pavement condition, and pavement characteristics of selected sections of Indiana highways (*7*). On the basis of earlier studies, maintenance activities were identified by pavement contract section units, which are smaller than the highway sections currently used by the Indiana Department of Highways (IDOH) (*1,3*). A contract section is the portion of highway pavement that is assigned to one contractor for a specific activity, such as resurfacing. The pavement characteristics within these sections are generally uniform. In contrast, a highway section may include a series of contract sections, each with different pavement characteristics.

The data base covered 10 out of 37 maintenance subdistricts in Indiana. It included two highway classes (Interstate and Other State Highways), three pavement types (flexible, rigid, and rigid with flexible overlay), and two climatic regions (north and south). In all, 550 contract sections were selected, including 126 sections in Interstate and 424 in Other State Highways (OSH). The 1984 and 1985 data on PCA Roadmeter roughness measurement (counts per mile) for each contract section were obtained from the computer files of IDOH's Division of Research and Training. The amount of routine maintenance applied between two dates of roughness measurements was determined from each subdistrict's crew day cards. Data on average daily traffic (ADT) and percentage of trucks were obtained from IDOH's Division of Planning.

Four routine maintenance activities were considered in this research: shallow patching, deep patching, sealing longitudinal cracks and joints, and sealing cracks. Pavement contract sections were grouped by the type of routine maintenance applied during the study period. It was determined that very few sections received only joint and crack sealing activities; these procedures were usually performed along with the other types of maintenance. Therefore, to include implicitly the effect of the expenditure level of different maintenance activities on pavement service life, the following two maintenance categories were used in the analysis:

1. Shallow and deep patching (*P*), and
2. Patching and joint and crack sealing (PS). (For flexible and overlaid pavements, PS means patching and crack sealing.)

The conceptual relationship between pavement roughness and pavement age, presented in Figure 2, was assumed valid for small variations in traffic loading. Therefore, both traffic and maintenance expenditure were divided into two levels—low and high—to examine the relationship separately for each

TABLE 1 CUTOFF VALUES BETWEEN LOW AND HIGH LEVELS OF MAINTENANCE EXPENDITURE AND TRAFFIC LOADING

Highway Class	Pavement Type	Maintenance Expenditure ($/lane-mile/year)		Traffic ESAL (thousands)
		Patching and Jt. & Crack Sealing	Patching	
Interstate	Rigid	165	80	400
	Overlaid	255	90	215
Other State Highways	Flexible	412	122	20
	Rigid	355	196	55
	Overlaid	268	102	35

traffic/maintenance level combination. Mean annual ESAL values were used as a measure of traffic loading and were computed on the basis of available ADT and truck percentage data. To represent both north and south regions in Indiana with adequate sample sizes, the cutoff value between the low and high traffic levels for each highway class/pavement type combination was computed as follows:

$$\text{Cutoff value} = (\text{Avg. ESAL in North} + \text{Avg. ESAL in South})/2$$

The same procedure was used to determine low and high expenditure levels for each maintenance category. The cutoff values between low and high levels of maintenance expenditure and traffic loading for each highway class/pavement type combination are listed in Table 1.

A preliminary analysis of pavement contract sections that did not receive maintenance work during the study period was conducted to investigate the possibility of developing zero-maintenance curves. The available information was insufficient to predict the effect of zero maintenance on pavement service life, so these contract sections were excluded from further analysis.

EFFECT OF PAVEMENT TYPE ON RELATIONSHIP BETWEEN PAVEMENT ROUGHNESS AND PAVEMENT AGE

As shown in Figure 2, the relationship between pavement roughness and age was assumed to be nonlinear. Since the definition of pavement roughness varies depending on whether the measuring system is response-type or pavement profile, this assumption needed to be tested. Therefore, the data were analyzed separately by maintenance category, climatic region, and highway class/pavement type combination. To evaluate the effects of traffic and maintenance expenditure levels, the data were further subdivided based on the following traffic/maintenance level combinations:

- LL—low maintenance expenditure, low traffic;
- LH—low maintenance expenditure, high traffic;
- HL—high maintenance expenditure, low traffic; and
- HH—high maintenance expenditure, high traffic.

No observations were available in some cells, especially for the Interstate highway class. Also, because very few contract sections were found, these cases were not considered in the analysis. Regression analysis was performed for the remaining traffic/maintenance level combinations using pavement roughness as the dependent variable and pavement age as the independent variable.

In most instances, the general goodness-of-fit represented by the coefficient of multiple determination (R^2) was used to select the best model. For each case, linear and nonlinear models were developed and the R^2 values of these models were compared. The relationship between pavement roughness and age was found to be more related to pavement type than to region, highway class, maintenance category, or traffic/maintenance level combination. Therefore, the following general regression models were adopted:

For flexible and rigid pavements:

$$\text{RN} = a + b(\text{age}) \quad (1)$$

For overlaid pavements:

$$\log_{10}(\text{RN}) = c + d(\text{age}) \quad (2)$$

where

RN = roughness measurement in 1985 (counts/mi),
age = pavement age since construction or resurfacing (yr), and
a, b, c, d = regression parameters.

From Equations 1 and 2, it can be stated that the relationship between pavement roughness and age was found linear for flexible and rigid pavements and nonlinear for overlaid pavements.

PREDICTION MODELS FOR EFFECTS OF ROUTINE MAINTENANCE EXPENDITURE LEVEL ON PAVEMENT SERVICE LIFE

Two general prediction models were developed to determine whether pavement age or total accumulated ESAL at resurfacing is a better representation of pavement service life. In addition to maintenance expenditure level and climatic region, pavement age and ESAL were considered in the first model and total accumulated ESAL was considered in the second model. (ESAL was included in the first model to test the effect of variations in annual traffic loading.) Pavement roughness was used as the dependent variable in both models. Furthermore, the models were developed by routine maintenance category and for each highway class/pavement type combination.

The two models were compared on the basis of two criteria:

1. The coefficient of multiple determination (R^2), and
2. The level of significance of pavement age and ΣESAL.

In general, a much higher R^2 was obtained for the first model than for the second. Pavement age was more significant than ΣESAL in all cases except Interstate rigid pavements. In many cases, especially for OSH pavements, ΣESAL was found not significant at a level of significance of $\alpha = 0.10$. Pavement age was therefore considered more suitable than ΣESAL to represent pavement service life. This conclusion was confirmed by the observation made by Schoenberger (*8*).

On the basis of this finding, linear prediction models were developed for flexible and rigid pavements and nonlinear models for overlaid pavements. To obtain the best models, the following steps were taken:

1. Insignificant models were excluded on the basis of a level of significance, with $\alpha = 0.05$.
2. For OSH pavements, separate models were developed for each region because R^2 values of these models were found not high when region was used as a dummy variable. Region was retained as a dummy variable in Interstate models because of the limited number of observations and the limited amount of routine maintenance work on these pavements regardless of region.
3. If a model was found significant but the variable of expenditure level was not found significant at $\alpha = 0.05$, then the model was eliminated.
4. The effect of patching was found not significant in all models. In some cases, mainly in rigid pavement models, patching expenditure level was found positively correlated with pavement roughness.
5. The remaining significant models in which ESAL was found insignificant at $\alpha = 0.10$ were reexamined after excluding this variable.

On the basis of these steps, the following regression models were adopted:

For Interstate overlaid pavements:

$$\log_{10}(\text{RN}) = 2.9 - 0.002\ \text{PS} + 0.19\ \text{age} - 0.004\ \text{ESAL} + 0.124\ Z \quad (3)$$

For OSH flexible pavements—north:

$$\text{RN} = 1{,}551 - 1.23\ \text{PS} + 57.1\ \text{age} - 15\ \text{ESAL} \quad (4)$$

For OSH overlaid pavements—north:

$$\log_{10}(\text{RN}) = 2.81 - 0.0005\ \text{PS} + 0.047\ \text{age} \quad (5)$$

where

PS = patching and joint and crack sealing expenditure level ($/lane-mi/yr),
ESAL = mean annual equivalent single-axle load (thousands), and
Z = dummy variable representing climatic region: 0 for north and 1 for south.

Table 2 provides a summary of the regression characteristics of the models presented in Equations 3 to 5. The models in which ESAL was found significant, Models 3 and 4, were further investigated. After omitting the ESAL variable from both models, R^2 in the Interstate overlaid model decreased from 0.95 to 0.91 and R^2 in the OSH flexible model decreased from 0.53 to 0.42. The decrease in R^2 in the Interstate overlaid model is so much less than that of the OSH flexible model because, as shown in Table 2, ESAL was found more significant in Equation 4 than in Equation 3.

TABLE 2 STATISTICAL CHARACTERISTICS OF PAVEMENT SERVICE LIFE PREDICTION MODELS (EQUATIONS 3–5)

Criterion	Eq. 3	Eq. 4	Eq. 5
Number of Observations	10	19	19
Coeff. of Determination (R^2)	0.95	0.53	0.77
Adjusted Coeff. (adj. R^2)	0.93	0.47	0.76
Linearity Test			
F Value	24.32	5.67	26.95
α Level	0.002	0.008	0
Significance Test for Coefficients			
PS			
F Value	15.15	5.18	2.89
α Level	0.012	0.040	0.100
Age			
F Value	14.81	10.98	48.55
α Level	0.012	0.005	0
ESAL			
F Value	4.46	3.71	-
α Level	0.090	0.070	-
Region			
F Value	0.80	-	-
α Level	0.410	-	-

On the basis of these findings, separate models were developed for low and high traffic loading levels for OSH flexible pavements in the north. ESAL was excluded from the Interstate overlaid model because of the limited number of observations and because eliminating ESAL did not significantly affect R^2. The resulting models are given in Equations 6 to 8:

For Interstate overlaid pavements:

$$\log_{10}(\text{RN}) = 2.5 - 0.001\ \text{PS} + 0.09\ \text{age} - 0.156\ Z \quad (6)$$

For OSH flexible pavements—low traffic level—north:

$$\text{RN} = 1{,}521 - 1.24\ \text{PS} + 48\ \text{age} \quad (7)$$

For OSH flexible pavements—high traffic level—north:

$$\text{RN} = 497 - 0.45\ \text{PS} + 85\ \text{age} \quad (8)$$

The statistical characteristics of the models presented in Equations 6 to 8 are given in Table 3. Equations 5 to 8 were employed to relate the time of resurfacing to routine maintenance expenditure level.

APPLICATION OF PAVEMENT SERVICE LIFE PREDICTION MODELS

Knowledge of the effects of routine maintenance on pavement service life is important to the management of highway pavements at both network and project levels. One application of the prediction models developed in this research was esti-

TABLE 3 STATISTICAL CHARACTERISTICS OF PAVEMENT SERVICE LIFE PREDICTION MODELS (EQUATIONS 6–8)

Criterion	Eq. 6	Eq. 7	Eq. 8
Number of Observations	10	13	6
Coeff. of Determination (R^2)	0.91	0.41	0.75
Adjusted Coeff. (adj. R^2)	0.88	0.36	0.68
Linearity Test			
F Value	19.63	3.49	4.39
α Level	0.002	0.07	0.13
Significance Test for Coefficients			
PS			
F Value	8.31	3.34	0.29
α Level	0.028	0.098	0.63
Age			
F Value	29.39	4.77	8.48
α Level	0.002	0.054	0.06
Region			
F Value	8.85	-	-
α Level	0.025	-	-

mation of the need for resurfacing under different routine maintenance expenditure levels. As shown in Figure 2, pavements need resurfacing when surface roughness reaches the terminal value. Terminal roughness (RN_T) can be defined as the roughness level at which a pavement section's serviceability is too low and, hence, the pavement is in need of improvement.

Earlier studies (*9,10*) indicate that PSI values of 2.0 for secondary roads and 2.5 for Interstate and primary highways can be considered minimum values of acceptable pavement serviceability. In this research, a terminal serviceability index of 2.5 was used for Interstate pavements and 2.2 for OSH pavements.

Three successive studies were conducted by Purdue University and IDOH (*11, 12, 13*) to establish a comprehensive model of statistical correlation between Roadmeter roughness numbers and PSI for the Indiana state highway system. The results of this research are given in Equations 9 and 10:

For flexible and overlaid pavements:

$$PSI = 8.72 - 1.96633 * \text{Log}_{10}(RN) \quad (9)$$

$r^2 = 0.71$

For rigid pavement:

$$PSI = 11.73 - 2.83369 * \text{Log}_{10}(RN) \quad (10)$$

$r^2 = 0.68$

where r^2 equals coefficient of simple determination.

The suggested terminal serviceability indices were used in Equations 9 and 10 to determine the terminal roughness values. The results were 1,460 counts/mi for Interstate overlaid pavements, 2,070 for OSH flexible and overlaid pavements, 1,808 for Interstate rigid pavements, and 2,307 for OSH rigid pavements. Since prediction models were not developed for rigid pavements, only the first two terminal values were used to determine the time of resurfacing or pavement improvement.

The prediction models in Equations 5 to 8 were used to compute pavement roughness under low and high PS expenditure levels and for different pavement ages. In these models, $200 and $300/lane-mi/yr were selected to represent low and high expenditure levels, respectively, for Interstate overlaid pavements. Because routine maintenance expenditure level on OSH pavements was found higher than that on Interstate pavements, $300 and $600/lane-mi/yr were selected to represent low and high PS expenditure levels for OSH flexible pavements. The corresponding values for OSH overlaid pavements were $150 and $450/lane-mi/yr. The terminal roughness values were then used to determine the pavement service life or resurfacing timing under each expenditure level.

The effects of routine maintenance expenditure level on pavement roughness and consequently on resurfacing decisions can be best demonstrated through the graphical presentations in Figures 3 to 7. These figures clearly show that pavement service life increases as the maintenance expenditure level increases. However, the amount of this increase varies. For example, as shown in Figures 3 and 7, if PS expenditure increases from low to high, the increase in service life for Interstate and OSH overlaid pavements is about 1 yr and 3.3 yr, respectively. It should be pointed out that service lives of Interstate and OSH pavements cannot be directly compared because of the difference in traffic and maintenance expenditure levels.

The results can be used to evaluate the effect of the region on resurfacing needs. It was found that pavements in the northern region need resurfacing earlier than pavements in the southern region, possibly due to the more severe weather in the northern region. At a low expenditure level ($200/lane-mi/yr), Interstate overlaid pavements need resurfacing after 9.7 yr in the north and 11.4 yr in the south (see Figures 3 and 4).

Figures 5 and 6 demonstrate the effect of traffic loading on expenditure levels. If PS expenditure increases from $300 to $600/lane-mi/yr, the increase in service life of OSH flexible pavements for low traffic loading is approximately 8 yr, using Equation 7. The corresponding value for high traffic loading is 1.6 yr, using Equation 8. The difference indicates the aggregated effect of higher traffic loading on pavement surface condition. Consequently, highly travelled OSH pavements require more frequent maintenance or resurfacing than those with low traffic loading.

To indicate the variability of predicted pavement service life values, prediction bands were developed for the effect of each PS expenditure level in Figures 3 to 7. The prediction bands were obtained by adding and subtracting one standard error of estimates of the model parameters. In general, the prediction bands were wide and overlapped in the same figure. Moreover, their width increased as pavement age increased; in other words, the models became less predictable as pavement age increased. Consequently, the results cannot be treated as entirely conclusive.

The results presented in this paper are applicable at an aggregated network level; they cannot be used in the actual scheduling of individual resurfacing projects. Resurfacing decisions for individual sections should be based on a comparison of resurfacing cost and routine maintenance cost along

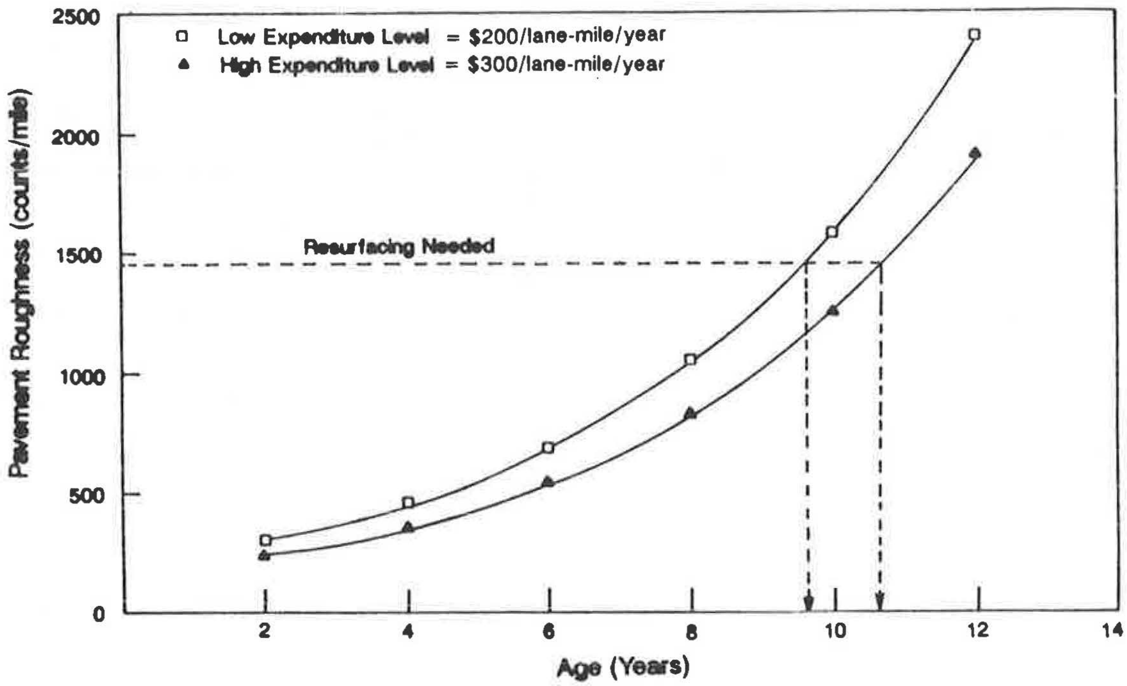


FIGURE 3 Estimated effect of patching and crack sealing expenditure level on service life of Interstate overlaid pavement in northern region (Equation 6).

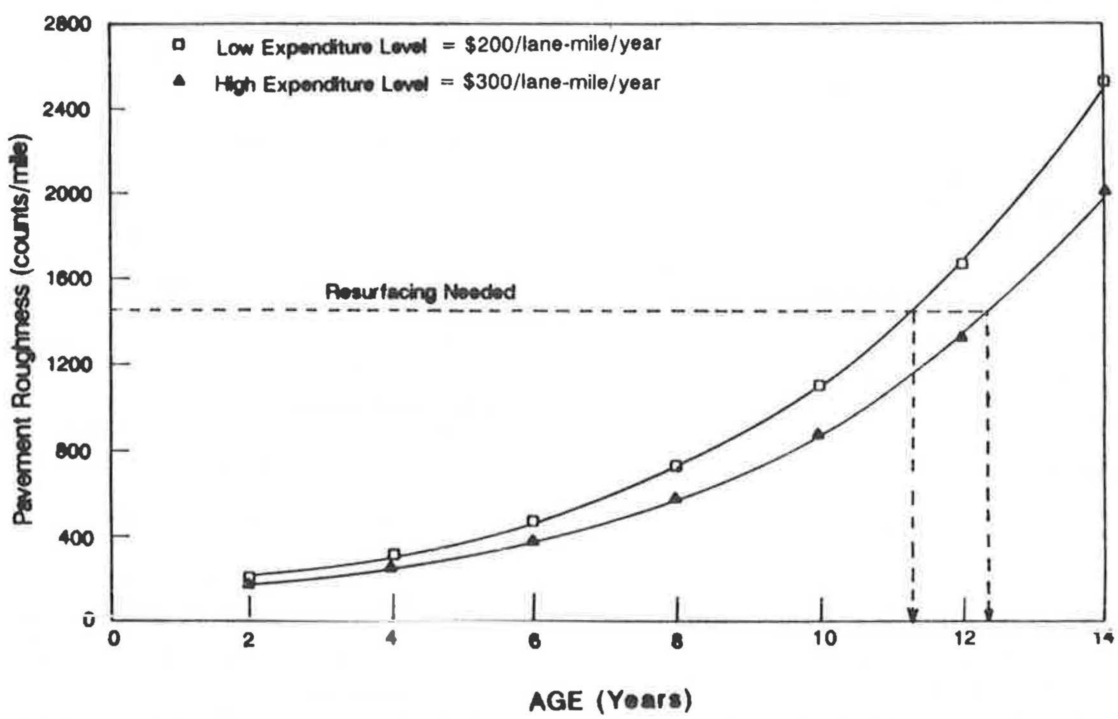


FIGURE 4 Estimated effect of patching and crack sealing expenditure level on service life of Interstate overlaid pavement in southern region (Equation 6).

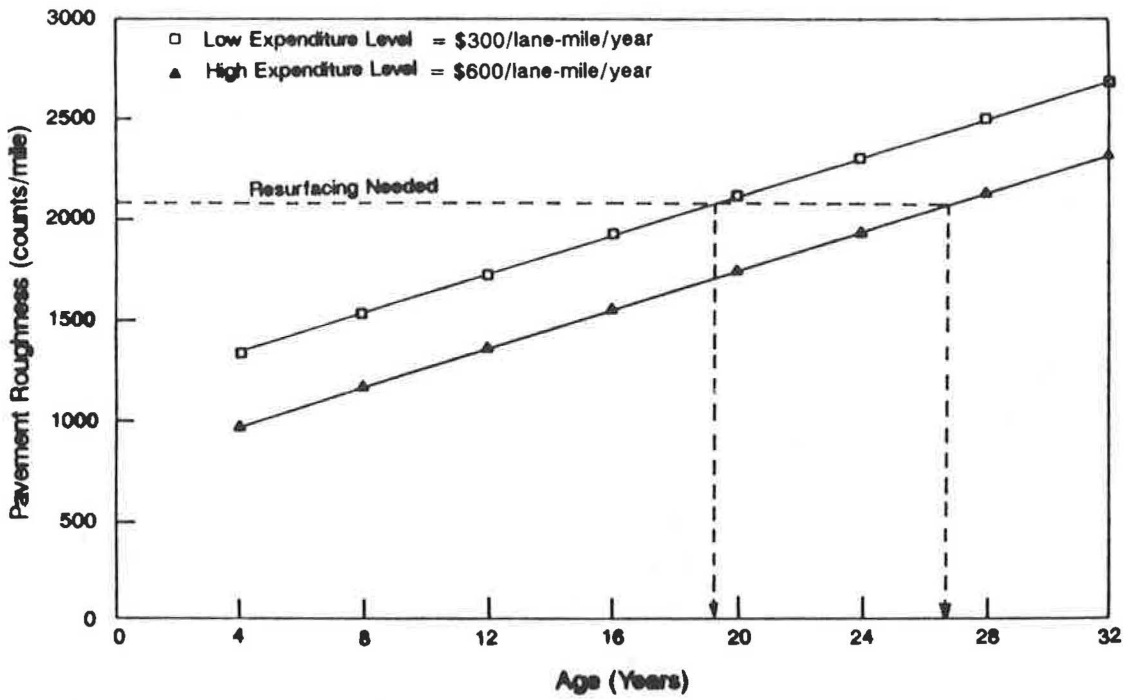


FIGURE 5 Estimated effect of patching and crack sealing expenditure level on service life of OSH flexible pavement in northern region—low traffic level (Equation 7).

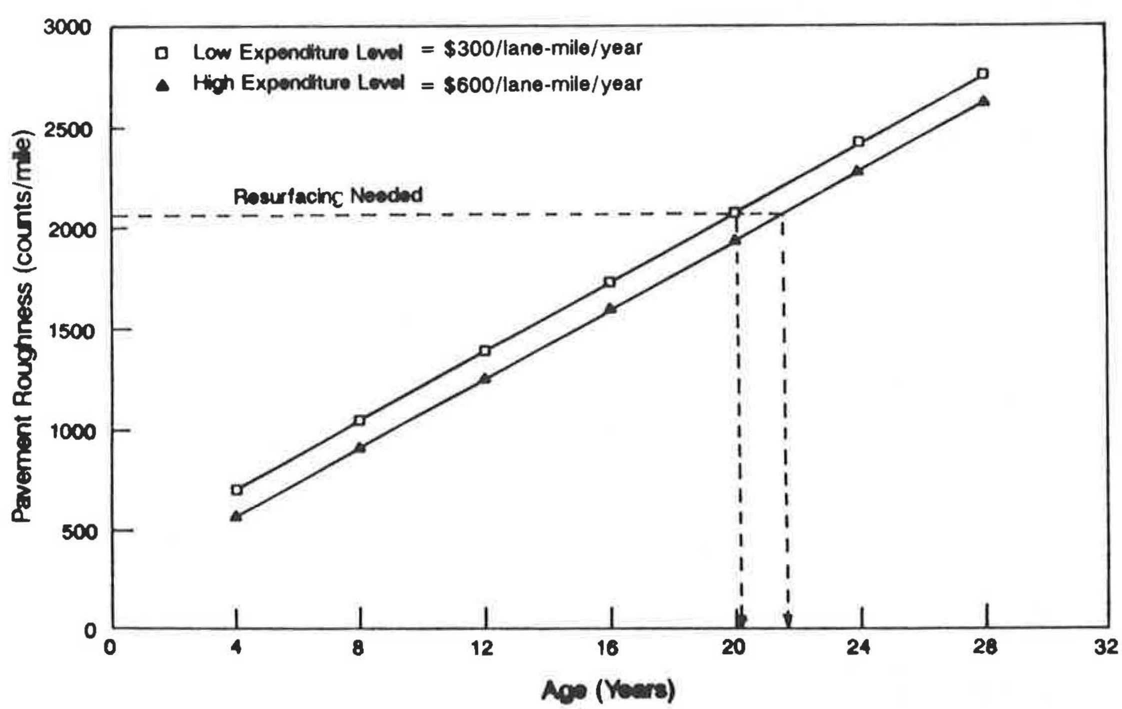


FIGURE 6 Estimated effect of patching and crack sealing expenditure level on service life of OSH flexible pavement in northern region—high traffic level (Equation 8).

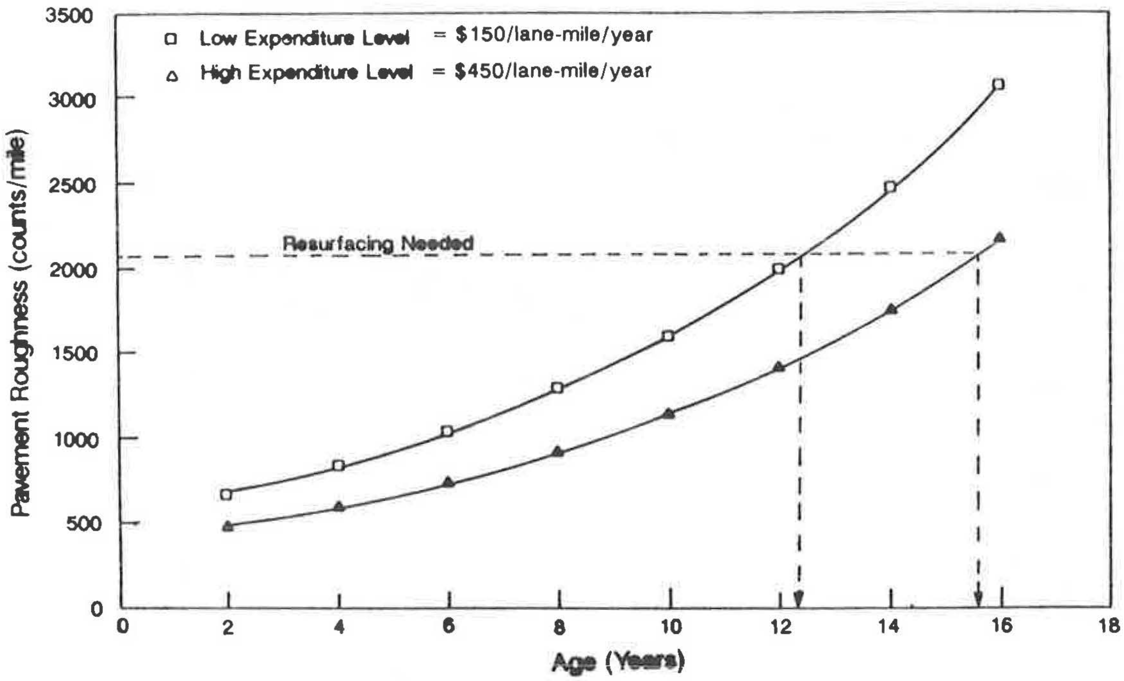


FIGURE 7 Estimated effect of patching and crack sealing expenditure level on service life of OSH overlaid pavement in northern region (Equation 5).

with a consideration of appropriate resurfacing design procedures. The prediction models can provide guidance in the preliminary analysis of pavement life-cycle costing.

To improve the prediction models developed in this research, the following factors should be considered:

- Thickness of overlay,
- Flexible pavement structural capacity,
- Rigid pavement slab thickness,
- Rigid pavement type (jointed plain concrete, jointed reinforced concrete, or continuous reinforced concrete), and
- Resurfacing cost and resurfacing design procedures.

SUMMARY AND CONCLUSIONS

The effects of routine maintenance expenditure on pavement service life were examined in this paper. The relationship between pavement roughness and pavement age was investigated under different traffic/maintenance expenditure level combinations. The relationship was found linear for flexible and rigid pavements and nonlinear for overlaid pavements. It was also determined that, for a small range of traffic loading, pavement age was a better variable than total accumulated ESAL to explain variations in pavement roughness.

Prediction models were used to examine the effect of maintenance expenditure level on pavement service life. The patching expenditure level was found insignificant in all models. Models in which mean annual ESAL was highly significant were reexamined, and separate models were developed for low and high traffic levels. The results demonstrated that resurfacing can be deferred or postponed by increasing the maintenance expenditure level. Routine maintenance was more effective in increasing the service life of OSH pavements than Interstate pavements. Also, it was found that pavements in the northern region needed resurfacing earlier than those in the southern region.

The prediction bands of the models were found to be wide, and their width increased as pavement age increased. Therefore, the results of the models cannot be treated as entirely conclusive. The models presented are applicable only to network-level decision making and should not be used to make resurfacing decisions for individual sections. To improve pavement service life prediction models, factors such as pavement thickness and cost of resurfacing should also be considered.

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