

Effect of Routine Maintenance on Pavement Roughness

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This paper presents a study of the relationship between routine maintenance expenditure level and pavement roughness. A database by contract section was developed for the state highway system of Indiana. Covariance analysis was performed to test the effect of climatic region. Regression models were developed to examine the effect of routine maintenance expenditure level on rate of change in pavement roughness. Two highway classes and three pavement types were considered in the analysis. The database included a total of 550 pavement contract sections. The results can be used to develop an effective maintenance program.

Ideally, a maintenance management system (MMS) is an integral part of a pavement management system (PMS). An important purpose of the maintenance management component in a PMS is to monitor the costs associated with providing various levels of serviceability for any given situation. The costs are dependent on the type and level of maintenance activity, which can in turn affect pavement performance in terms of the rate of serviceability loss or the change in surface roughness for a pavement.

The interest in MMS is largely motivated by a desire to obtain a greater degree of control and approach standardization in order to manage better such resources as labor, materials, and equipment (1). Many factors make the task of managing routine maintenance activities difficult. First, it is difficult to quantify the benefit of changing existing practices or choice of treatment. Also, systematic data collection is rarely undertaken to evaluate the differences between alternative maintenance treatments for any given pavement defect in terms of overall cost-effectiveness. Furthermore, the scope of maintenance involves many activities over thousands of miles of roads that must be maintained every year.

Routine maintenance represents a large percentage of the total highway expenditures of the Indiana Department of Highways (IDOH). This level of routing maintenance expenditure is typical of other state highway departments in the United States and of regional and national highway authorities in most countries in Europe (2). For that reason, the IDOH has developed a MMS for programming, scheduling, and monitoring routine maintenance operations. Several studies have been conducted at Purdue University through the Joint Highway Research Project (JHRP) to improve the efficiency of the existing MMS (3, 4).

The purpose of the present research effort was to study the effect of various routine maintenance expenditure levels on pavement condition in terms of surface roughness. Pavement roughness was used as a direct quantitative measure of pavement performance instead of Present Serviceability Index (PSI). This was based on the results of several studies (5, 6) concluding that in many instances the use of roughness measurements alone is sufficient for predicting the serviceability index.

To accomplish the main objective, a database was developed for pavement routine maintenance, pavement condition, and pavement characteristics. The appropriate data were collected based on construction contract sections. A contract section is that portion of a highway pavement that is contracted out to one contractor for a specific activity such as resurfacing. The pavement characteristics within a contract section are generally uniform. In contrast, a highway section may stretch from county line to county line and may include a series of different contract sections with different pavement characteristics.

DEVELOPMENT OF DATABASE

Based on the findings of previous studies (3, 4, 7, 8) in Indiana, two regions, two highway classes, and three pavement types were considered. The two highway classes are interstate and other state highways (OSH). The three pavement types are flexible pavements, rigid pavements, and rigid pavements with bituminous overlay. The database was developed from three sources of information: routine maintenance records, roughness measurement records, and road life records.

Design of Experiment

The IDOH has six districts. Five districts have six subdistricts each, and one district has seven subdistricts, for a total of thirty-seven subdistricts. In each subdistrict, there are three to four units that actually perform the field maintenance work. In the present study, the subdistrict was considered the appropriate management unit. Information had to be extracted from several thousand crew day cards recorded by subdistricts. The crew day cards provide a means of authorizing work to be done and a record of work completed (9). Each crew day card represents one eight-hour day of any maintenance activity. Ten subdistricts were selected for the analysis based on their fulfillment of the following criteria:

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1. to include sufficient sections from interstate highways;
2. to represent the administrative system so that at least one subdistrict was selected from each district;
3. to represent the entire state geographically;
4. to cover both climatic regions in the state (North and South); and
5. to avoid subdistricts that have a dense highway network, such as the Indianapolis subdistrict.

Finally, six subdistricts were selected from the South region and four subdistricts from the North region. Figure 1 shows the locations of the selected subdistricts.

Selection of Contract Sections

The two most recent roughness measurements (1984, 1985) in counts/mile were used. Only those contract sections that did not receive any major maintenance or resurfacing between the two roughness measurements were selected. The data on roughness measurement on each contract section for 1984 and 1985, along with such other information as contract number, contract length, surface type, landmarks, number of lanes in each direction, and date of construction or last major maintenance, were recorded in a newly created "roughness file."

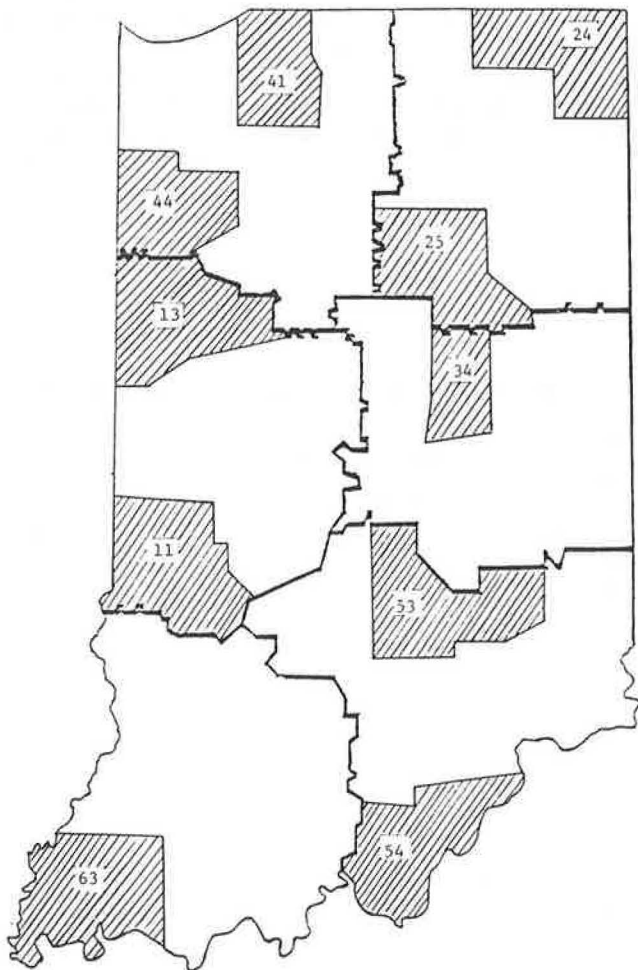


FIGURE 1 Locations of subdistricts included in the study.

A total of 550 contract sections were selected, including 126 sections in interstate and the remaining sections in other state highways (OSH).

Routine Maintenance Quantities

The amount of routine maintenance applied between two dates of roughness measurements was determined from crew day cards obtained from each subdistrict considered. A total of about ten thousand crew day cards were analyzed. Cards with missing information, such as highway number, county number, or location of the work, were excluded.

Pavement routine maintenance activities considered in this paper were categorized in two groups: (1) patching that consists of shallow patching (Activity 201) and deep patching (Activity 202); and (2) joint and crack sealing that consists of sealing longitudinal cracks and joints (Activity 206) and sealing cracks (Activity 207).

The relevant information extracted from the crew day cards included activity type, date of work, location of work, and the number of production units accomplished. The information was recorded in a newly created "routine maintenance file."

Routine Maintenance Amount by Contract Sections

Both roughness and routine maintenance records have generally the same inventory data, including the following common information:

1. highway class and number
2. county number
3. subdistrict number
4. district number

Using this information, it was possible to determine the amount of routine maintenance work done on a contract section. Two location demarcation scales were established for each highway in each subdistrict. The first scale was called the Contract Section Scale. It used the identified mileposts and determined contract length in lane-miles. The second scale, called Landmarks Scale, used mileposts and the distance between two successive landmarks. Landmarks included intersections, bridges, county lines, and rivers.

Having established the two scales, routine maintenance quantity on each card was distributed according to the contract length by activity. In most cases, the location of routine maintenance was recorded between landmarks containing more than one contract section. In such cases, the Landmarks Scale was applied, and the routine maintenance work was distributed in proportion to the length of the different contract sections. If the location of routine maintenance work was defined by mileposts within a contract section, then the quantity of the work was assigned directly to the corresponding contract section. This occurred mainly with interstate highways because in Indiana only interstates have mileposts.

Finally, the routine maintenance quantities were summed for each contract section and recorded along with roughness measurement and other information in a single file containing routine maintenance and roughness data. Information on

average daily traffic (ADT) and percent of trucks obtained from the Division of Planning of the IDOH was added to the database.

Routine Maintenance Expenditure

After the quantity of each routine maintenance activity on each contract section was determined, the dollar values of maintenance activities performed on contract sections were obtained by multiplying the quantities by appropriate unit costs developed by Sharaf (10) and IDOH (11). The routine maintenance expenditure was calculated in dollars/lane-mile/year. The cost items considered were labor, materials, and the cost of motor fuel consumed by maintenance equipment and vehicles. These costs did not include those for overhead and equipment depreciation. Cutting relief joints (Activity 209), joint and bump burning (Activity 214), and other functions (Activity 219) were not considered because it was found that very few crew day cards had these activities for the selected subdistricts during the study period.

DATA ANALYSIS

One of the major factors causing pavement distresses is the climate. A pavement is affected not only by the weather but also by such related factors as deicing chemical agents. In this study, two climatic regions, the Northern region and the Southern region, were considered.

A statistical test was conducted to determine whether the data in both climatic regions can be analyzed as one data set or not. The two southernmost subdistricts (numbers 54 and

63) were selected to be tested against the two northernmost subdistricts (numbers 24 and 41) as shown in Figure 1. Since sufficient interstate sections were not available in these subdistricts, only other state highways were considered in the analysis. Pavement sections were grouped based on the type of routine maintenance that was applied during the study period. Table 1 shows the distribution of pavement contract sections by region and by routine maintenance category for each pavement type. The number of sections that received sealing or zero maintenance was very few, and in some cells no observations were available. Therefore, it was decided to use two routine maintenance categories (patching and patching plus joint and crack sealing) in the analysis.

Analysis of covariance technique was used to analyze data. Pavement age and cumulative equivalent single axle load (Σ ESAL) were considered quantitative variables and climatic region and routine maintenance category as qualitative variables. Pavement roughness in 1985 was used as the dependent variable. As recommended by Anderson and McLean (12) and to develop the covariance models for different pavement types, the following two tests were made on the dependent variables.

1. *Normality Test*: Since the number of observations in each of the considered cells was less than 50, the Wilk-Shapiro (12) test was used. In some cases, the dependent variable was not found normally distributed even at the level of $\alpha = .01$. So, \log_{10} transformation was tried on the dependent variable, and normality was indicated in all cases at $\alpha \geq .10$.

2. *Homogeneity of Variances Test*: Since the number of observations was different from cell to cell (unbalanced design), the homogeneity of variances was checked by performing the Burr-Foster (12) test. The variances of the dependent variable were found homogenous at the level of $\alpha = .01$ in all cases.

TABLE 1 DISTRIBUTION OF CONTRACT SECTIONS BY CLIMATIC REGION BY ROUTINE MAINTENANCE CATEGORY FOR EACH PAVEMENT TYPE

Pavement Type	Routine Maintenance Category	Northern Region			Southern Region		
		Subdistricts		Total Data Points	Subdistricts		Total Data Points
		Angola (24) ^a	Laporte (41) ^a		New Albany (54) ^a	Evansville (63) ^a	
Flexible	Patching	10	9	19	11	4	15
	Patching and joint & crack sealing	5	1	6	4	10	14
	Joint & crack sealing	1	1	2	2	1	3
	None	—	4	4	1	—	1
Rigid	Patching	2	8	10	6	4	10
	Patching and joint & crack sealing	—	3	3	—	12	12
	Joint & crack sealing	—	—	—	—	8	8
	None	—	1	1	—	—	—
Overlaid	Patching	10	7	17	1	4	5
	Patching and joint & crack sealing	1	7	8	1	11	12
	Joint & crack sealing	—	5	5	—	—	—
	None	—	—	—	—	—	—

^aCode number of subdistrict.

Having met the normality and homogeneity tests, the following covariance model was adopted:

$$\log_{10}(RN_{85}) = \mu + R + RM + R * RM + \text{Age} + \Sigma\text{ESAL} + \varepsilon \quad (1)$$

where

- RN_{85} = roughness measurement in 1985 in counts/mile;
 μ = overall mean;
 R = climatic region;
 RM = routine maintenance category;
 $R * RM$ = interaction between region and routine maintenance;
 age = pavement age since construction or last major maintenance in years;
 ΣESAL = total accumulated ESAL; and
 ε = random error component.

Table 2 shows the statistical characteristics of covariance analysis for each pavement type. The major findings of this analysis are summarized below.

1. The regional effect was significant in all cases at the level of $\alpha < .10$. Based on this major finding, regression models were developed in the next section, and regional effect was considered as a main factor in these models.

2. Routine maintenance category (RM) was found to be not significant with respect to roughness measurements in 1985. This was because there were only two categories of maintenance considered and the measurements were only for one year. However, the interaction between climatic region and routine maintenance category was significant at $\alpha < .25$. This level of α was chosen because the recording of the location of routine maintenance work in most of the crew day cards was not precise. In addition, the initial data analysis was conducted as an overall test. Regression models were used to specify the trend of this interaction. The significance of the interaction between climatic region and routine maintenance category implies that effects of RM category differed between North and South regions.

3. The effects of pavement age and ΣESAL were significant at $\alpha \leq .10$, except for rigid pavements. A part of the reason could be that most rigid pavement sections are very old in both regions.

It should be noted that because of data limitations, the preceding analysis was conducted with only four out of ten subdistricts in the database.

REGRESSION MODELS FOR ROUTINE MAINTENANCE EXPENDITURE AND REGIONAL EFFECTS

Based on the results of covariance analysis, regression analysis was performed to study the effects of routine maintenance expenditure level and climatic region on pavement roughness. Rate of change in pavement roughness was used as the dependent variable in these models. Pavement sections with both negative and positive changes in roughness were considered in the analysis. Rate of change in pavement roughness was calculated as follows:

$$RRN = \frac{RN_{85} - RN_{84}}{RN_{84}} \quad (2)$$

where

- RRN = rate of change in pavement roughness
 RN_{84} = roughness measurement in 1984 (counts/mile); and
 RN_{85} = roughness measurement in 1985 (counts/mile).

Since PSI is highly correlated to pavement roughness, RRN can be used as a measure of pavement deterioration. In Equation 2, RN_{84} represents the effect of past maintenance on pavement condition, while $RN_{85} - RN_{84}$ represents the effect of routine maintenance that was applied between the two roughness measurements.

The analysis included data from all the selected subdistricts in both regions. Only those pavement sections that received patching (P) or patching and joint and crack sealing (PS) were analyzed. Five categories of highway class pavement type were included: interstate rigid pavement, interstate overlaid pavement, OSH flexible pavement, OSH rigid pavement, and OSH overlaid pavement. Three criteria were considered in selecting the best model: (1) the general goodness-of-fit represented by the coefficient of multiple determination (R^2); (2) the general linearity test for the model through the application of the general F -test, and (3) the significance of individual coefficients of the model through the t - or F -tests. These criteria were applied, and an attempt was made to have the same model type for the five categories to facilitate consideration of the effects of different factors.

After several trials, the following regression model appeared to satisfy most of the required conditions.

$$RRN = a + b \log_{10}(RM) + c(R) + d \log_{10}(RM) * (R) \quad (3)$$

TABLE 2 STATISTICAL CHARACTERISTICS OF COVARIANCE ANALYSIS BY PAVEMENT TYPE

Variables	Flexible Pavements (54) ^a		Rigid Pavements (35) ^a		Overlaid Pavements (42) ^a	
	F-Value	α -Level	F-Value	α -Level	F-Value	α -Level
Region	3.70	0.060	4.02	0.054	5.66	0.023
RM	0.15	0.702 ^b	0.36	0.551 ^b	0.15	0.701 ^b
Region * RM	1.61	0.211	6.19	0.019	2.48	0.124
Age	19.06	0.000	0.94	0.341 ^b	4.52	0.040
ΣESAL	2.69	0.108	0.07	0.796 ^b	4.48	0.041

NOTE: $\log_{10}(RN_{85})$ was used as the dependent or response variable.

^aNumber of observations.

^bThe variable is not significant at $\alpha < 0.25$.

where

RRN = rate of change in pavement roughness;
 RM = routine maintenance expenditure level (\$/lane-mile/Year) (this variable takes the symbol (P) for pavement sections that received patching and (PS) for sections that received patching and joint and crack sealing);

R = dummy variable to represent the region in which the pavement section is located: 0 for Northern region and 1 for Southern region; and

a, b, c, d = regression parameters.

A high level of confidence with $\alpha = .05$ was used to test the significance of all regression models. The following models were found significant.

For interstate rigid pavements:

$$RRN = 1.0 - 0.37 \log_{10}(PS) - 0.07 R \quad (4)$$

For interstate overlaid pavements:

$$RRN = 1.83 - 0.81 \log_{10}(PS) + 0.11 R \quad (5)$$

$$RRN = 0.27 - 0.20 \log_{10}(P) + 0.26 R \quad (6)$$

For OSH flexible pavements:

$$RRN = 1.5 - 0.49 \log_{10}(PS) + 2.19 R - 0.79 \log_{10}(PS) * R \quad (7)$$

$$RRN = 1.65 - 0.65 \log_{10}(P) - 0.94 R + 0.43 \log_{10}(P) * R \quad (8)$$

For OSH overlaid pavements:

$$RRN = 5.44 - 2.04 \log_{10}(PS) - 3.8 R + 1.5 \log_{10}(PS) * R \quad (9)$$

For OSH rigid pavements:

$$RRN = 0.62 - 0.15 \log_{10}(P) - 0.13 R \quad (10)$$

Only Equations 7, 8, and 9 included the interaction term (between routine maintenance expenditure level and region). This is because the routine maintenance expenditure level on OSH had a wider range. For example, the expenditure level of PS on OSH overlaid pavements varies between 100 and 750 \$/lane-mile/year, while on interstate overlaid, it varies between 150 and 400 \$/lane-mile/year.

A summary of the characteristics of the regression models are given in Tables 3 and 4, respectively. As shown in these tables, a relatively higher R^2 was obtained for interstate than OSH models. This may be due to the fact that interstate highways are mile-posted; so it was easier and more accurate to match routine maintenance locations with roughness measurements. Furthermore, the significance test for the coefficient b for the variable RM (routine maintenance expenditure level) showed a high level of confidence. The levels of significance of the region and interaction term were lower than that of the expenditure level. These variables, however, could be considered significant at a 90 percent level of confidence, as shown in Tables 3 and 4.

Two observations can be made regarding the insignificant models: (1) the number of available sections in the Northern region in some cases was very small; and (2) routine maintenance records in the Southern region were less organized, and the location of maintenance on these records was less accurate. Therefore, regression models were developed separately for Northern and Southern regions. Table 5 shows these statistical models. As shown in this table, in general, a higher R^2 was obtained for all category models in the North. Most of the category models in the Southern region were insignificant. In all these insignificant models, however, there is a consistent trend indicating the significance at a higher level of α . The primary reason of these results is the inaccuracy in determining the exact location and amount of maintenance activity.

TABLE 3 STATISTICAL CHARACTERISTICS OF PATCHING AND JOINT AND CRACK SEALING MODELS

Criterion	Interstate Rigid ($N = 27$) ^a	Interstate Overlaid ($N = 10$) ^a	OSH Flexible ($N = 44$) ^a	OSH Rigid ($N = 43$) ^a	OSH Overlaid ($N = 57$) ^a
Coefficient of determination (R^2)	0.30	0.86	0.46	0.07	0.32
Adjusted coefficient (adj. R^2)	0.27	0.84	0.43	0.05	0.30
Linearity test					
F -value	5.14	20.96	11.23	1.48	8.37
α level	0.014	0.001	0	0.24 ^b	0
Significance test for coefficients					
$\log_{10}(PS)$					
F -value	9.78	23.06	3.66	2.95	14.82
α value	0.005	0.002	0.063	0.093	0
Region					
F -value	1.15	7.71	6.20	0	7.86
α value	0.29 ^c	0.028	0.017	0.95 ^c	0.007
$\log_{10}(PS) * \text{Region}$					
F -value	—	—	5.24	—	7.27
α value	—	—	0.027	—	0.009

^aNumber of observations.

^bThe model is not significant at $\alpha > 0.05$.

^cThe coefficient is not significant at $\alpha > 0.10$.

TABLE 4 STATISTICAL CHARACTERISTICS OF PATCHING MODELS

Criterion	Interstate Rigid (<i>N</i> = 28) ^a	Interstate Overlaid (<i>N</i> = 21) ^a	OSH Flexible (<i>N</i> = 78) ^a	OSH Rigid (<i>N</i> = 44) ^a	OSH Overlaid (<i>N</i> = 47) ^a
Coefficient of determination (<i>R</i> ²)	0.13	0.61	0.21	0.25	0.09
Adjusted coefficient (adj. <i>R</i> ²)	0.06	0.59	0.18	0.23	0.07
Linearity test					
<i>F</i> -value	1.20	14.07	6.33	6.70	2.07
α level	0.33 ^b	0	0.001	0.003	0.14 ^b
Significance test for coefficients					
Log ₁₀ (<i>P</i>)					
<i>F</i> -value	1.27	10.88	16.17	6.37	3.71
α value	0.27 ^c	0.004	0	0.02	0.061
Region					
<i>F</i> -value	1.20	18.49	3.87	3.94	0.57
α value	0.28 ^c	0	0.053	0.05	0.45 ^c
Log ₁₀ (<i>P</i>) * Region					
<i>F</i> -value	1.26	—	3.12	—	—
α value	0.27 ^c	—	0.082	—	—

^aNumber of observations.^bThe model is not significant as α > 0.05.^cThe coefficient is not significant at α > 0.10.

IMPLICATIONS OF THE MODELS

The effects of routine maintenance expenditure level and climatic region on rate of change in pavement roughness (pavement deterioration) can best be demonstrated through examination of Figures 2 to 7. The *RRN* is positive in most cases, indicating that roughness increases regardless of maintenance expenditure level. The amount of this increase varies, however. It is clear that in most of the cases, *RRN* in the Northern region is higher than that in the Southern region, especially at a low expenditure level of routine maintenance. This may be because of a longer cold period and a greater amount of snowfall in the Northern region, requiring a higher level of maintenance. The validity of this conclusion can be supported by the fact, as reported by Fwa and Sinha (4), that the non-load-related damage responsibility in the Northern region is significantly higher than that in the Southern region. In some cases, as shown in Figures 3 and 4, *RRN* is higher in the Southern region. In these cases, it was found that the average pavement age of the analyzed sections in the Southern region was greater, and the average ESAL on these sections was also higher. For example, the average age of OSH flexible pavement sections in the Southern region that were patched and sealed was about twelve years, while it was nine years in

the Northern region. The corresponding average traffic levels were 209,000 and 151,000 accumulated ESAL, respectively.

It is obvious in Figures 2 to 7 that, as routine maintenance expenditure level increases, *RRN* decreases and the difference in pavement deterioration between the two regions becomes less. In some cases, as shown in Figures 5 and 6, at higher expenditure levels *RRN* in the Northern region is lower than that in Southern region. In some cases, in the North, pavement roughness decreased even at lower expenditure levels. These results may possibly reflect the higher maintenance quality and degree of supervision in the Northern region.

The discussion of the results in this paper leads to the concept of routine maintenance effectiveness. Maintenance effectiveness in this study can best be represented by the reduction in *RRN* as routine maintenance increased from one expenditure level to another. In general, the reduction in *RRN* in the Northern region was more than that in the Southern region if maintenance increased from one expenditure level to another, regardless of pavement type or maintenance activity. Furthermore, this reduction was noticeable or higher when the increase in expenditure took place at lower levels of maintenance. For example, as shown in Table 6, if *PS* expenditure level increased from 50 to 100 \$/lane-mile/year, the reductions in *RRN* for interstate overlaid in the Northern and Southern

TABLE 5 STATISTICAL MODELS FOR THE EFFECT OF ROUTINE MAINTENANCE EXPENDITURE LEVEL BY REGION

Routine Maintenance Variable	Pavement Type	Northern Region			Southern Region		
		Model	<i>R</i> ²	Adj. <i>R</i> ²	Model	<i>R</i> ²	Adj. <i>R</i> ²
Patching and joint and crack sealing	Interstate rigid	<i>RRN</i> = 1.14 - 0.43 log ₁₀ (<i>PS</i>)	0.50	0.46	<i>RRN</i> = 0.79 - 0.30 log ₁₀ (<i>PS</i>)	0.15	0.06
	Interstate overlaid	<i>RRN</i> = 2.20 - 0.97 log ₁₀ (<i>PS</i>)	0.94	0.90	<i>RRN</i> = 1.63 - 0.63 log ₁₀ (<i>PS</i>)	0.63	0.54
	OSH flexible	<i>RRN</i> = 1.50 - 0.49 log ₁₀ (<i>PS</i>)	0.21	0.17	<i>RRN</i> = 3.68 - 1.28 log ₁₀ (<i>PS</i>)	0.53	0.51
	OH rigid	<i>RRN</i> = 0.65 - 0.10 log ₁₀ (<i>PS</i>)	0.05 ^a	-0.03	<i>RRN</i> = 1.45 - 0.43 log ₁₀ (<i>PS</i>)	0.08 ^a	0.05
	OSH overlaid	<i>RRN</i> = 5.44 - 2.04 log ₁₀ (<i>PS</i>)	0.42	-0.38	<i>RRN</i> = 1.63 - 0.54 log ₁₀ (<i>PS</i>)	0.24	0.22
Patching	Interstate rigid	<i>RRN</i> = 5.10 - 2.30 log ₁₀ (<i>P</i>)	0.99	0.99	<i>RRN</i> = 0.27 - 0.05 log ₁₀ (<i>P</i>)	0.02 ^a	-0.02
	Interstate overlaid	<i>RRN</i> = 0.47 - 0.31 log ₁₀ (<i>P</i>)	0.47	0.42	<i>RRN</i> = 0.43 - 0.15 log ₁₀ (<i>P</i>)	0.38	0.29
	OSH flexible	<i>RRN</i> = 1.64 - 0.65 log ₁₀ (<i>P</i>)	0.28	0.26	<i>RRN</i> = 0.70 - 0.23 log ₁₀ (<i>P</i>)	0.05 ^a	0.02
	OSH rigid	<i>RRN</i> = 0.65 - 0.16 log ₁₀ (<i>P</i>)	0.33	0.28	<i>RRN</i> = 0.46 - 0.13 log ₁₀ (<i>P</i>)	0.08 ^a	0.04
	OSH overlaid	<i>RRN</i> = 0.86 - 0.29 log ₁₀ (<i>P</i>)	0.11	0.07	<i>RRN</i> = 0.65 - 0.23 log ₁₀ (<i>P</i>)	0.03 ^a	-0.02

^aThe model is not significant at α > .10.

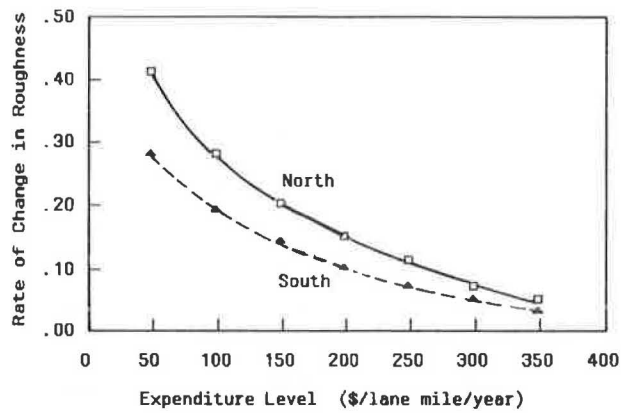


FIGURE 2 Effect of patching and joint and crack sealing expenditure level on interstate rigid pavement roughness.

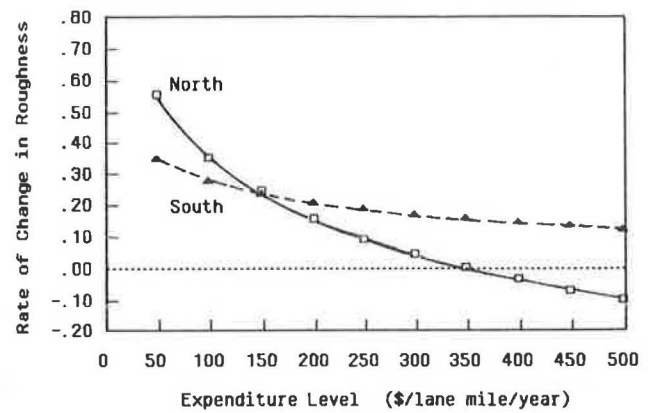


FIGURE 5 Effect of patching expenditure level on OSH flexible pavement roughness.

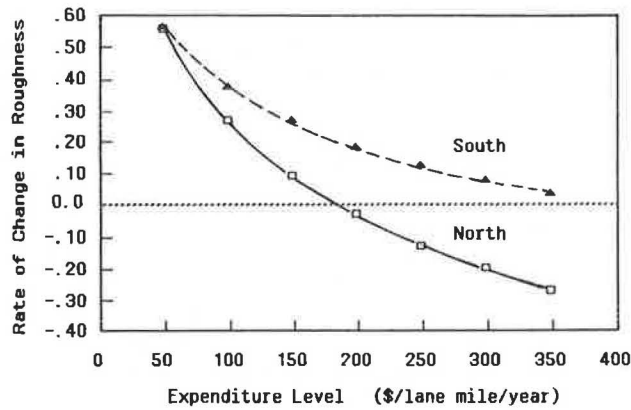


FIGURE 3 Effect of patching and joint and crack sealing expenditure level on interstate overlaid pavement roughness.

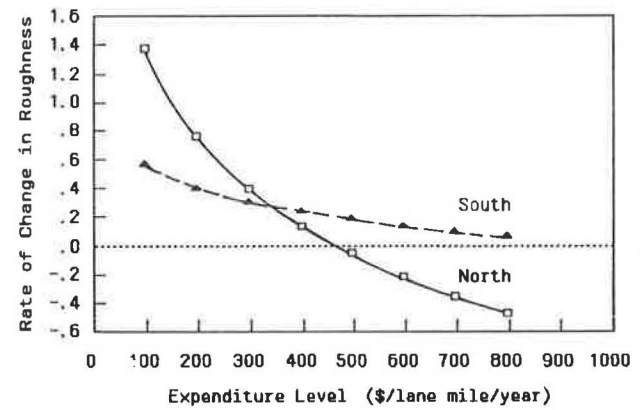


FIGURE 6 Effect of patching and joint and crack sealing expenditure level on OSH overlaid pavement roughness.

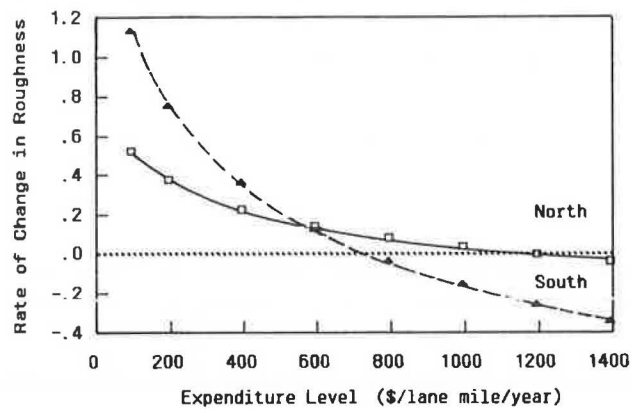


FIGURE 4 Effect of patching and joint and crack sealing expenditure level on OSH flexible pavement roughness.

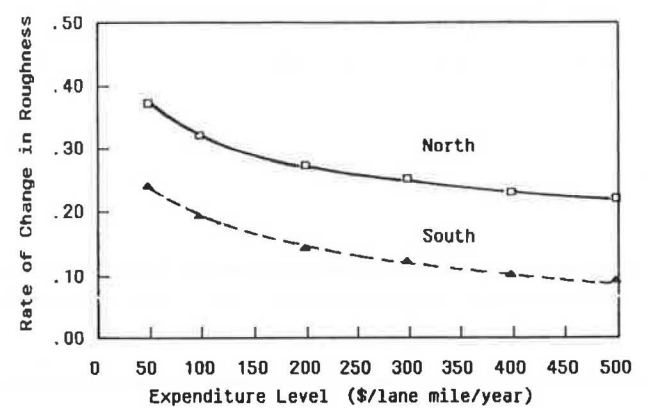


FIGURE 7 Effect of patching expenditure level on OSH rigid pavement roughness.

TABLE 6 REDUCTION IN RATE OF CHANGE IN PAVEMENT ROUGHNESS AS ROUTINE MAINTENANCE EXPENDITURE LEVEL CHANGES FOR INTERSTATE OVERLAID

Increase in Expenditure Level (from-to)	Reduction in Rate of Change in Pavement Roughness			
	Patching and Joint and Crack Sealing		Patching	
	North	South	North	South
50-100	0.29	0.19	0.09	0.05
100-150	0.17	0.11	0.05	0.03
150-200	0.12	0.08	0.04	0.02
200-250	0.10	0.06	0.03	0.01
250-300	0.07	0.05	0.03	0.01
300-350	0.07	0.04	0.02	0.01

TABLE 7 EFFECT OF CHANGES IN PATCHING EXPENDITURE LEVEL ON REDUCTION IN RATE OF CHANGE IN PAVEMENT ROUGHNESS FOR TWO PAVEMENT TYPES

Increase in Expenditure Level (from-to)	Reduction in Rate of Change in Pavement Roughness			
	OSH Flexible		OSH Rigid	
	North	South	North	South
50-100	0.20	0.07	0.05	0.05
100-150	0.11	0.04	0.03	0.03
150-200	0.09	0.03	0.02	0.03
200-250	0.06	0.02	0.01	0.01
250-300	0.05	0.02	0.01	0.01
300-350	0.04	0.01	0.01	0.01
350-400	0.04	0.01	0.01	0.01

regions were 0.29 and 0.19, respectively. In contrast, if *PS* expenditure level increased from 200 to 250 \$/lane-mile/year, the corresponding reduction values of *RRN* were 0.10 and 0.06, respectively.

A possible main conclusion is that maintenance effectiveness is higher in the Northern region than in the Southern region. This result confirmed what Fwa and Sinha (4) observed in an earlier study. They stated that the amount of pavement damage repaired (i.e., the amount of PSI-ESAL loss recovered) per dollar worth of maintenance work was greater in the Northern region.

The concept of maintenance effectiveness can be used to compare the effect of the same maintenance activity expend-

iture level on surface roughness of different pavement types. Table 7 shows the effect of changes in patching expenditure level on reduction in *RRN* for OSH flexible and rigid pavements. If patching expenditure level increased from 50 to 100 \$/lane-mile/year, the reductions in *RRN* for OSH flexible and rigid pavement in the Northern region were 0.20 and 0.05, respectively. In general, it was found that regardless of climatic region, highway class, or maintenance activity, the response of rigid pavement to changes in expenditure level is less than that of flexible or overlaid pavements.

Figures 8 and 9 show the effect of expenditure level of two maintenance policies (*P* and *PS*) on *RRN* for interstate rigid and OSH flexible pavements, respectively, in the Southern

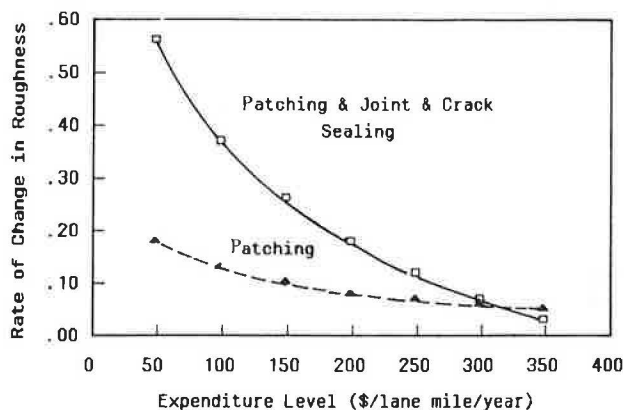


FIGURE 8 Effect of expenditure level of two maintenance policies on interstate overlaid pavement roughness.

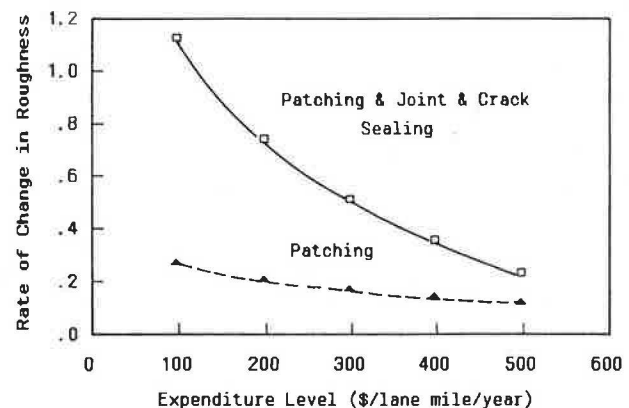


FIGURE 9 Effect of expenditure level of two maintenance policies on OSH flexible pavement roughness.

region. It is clear in these figures that regardless of highway class or pavement type, the effectiveness (slope of the curve) of using patching and sealing is higher than that of patching alone. The results show that adding joint and crack sealing to patching increases the maintenance effectiveness in reducing *RRN*. Hence, joint and crack sealing may have an important role as a preventive maintenance activity in improving pavement performance.

An important application of the results of this analysis is in assessment of the effect of climatic region, routine maintenance expenditure level, and their interaction on pavement performance in terms of surface roughness. The results can be used to help management at the central office monitor the surface condition of the highway network within a subdistrict on a periodic basis. In addition, with knowledge of the surface roughness of pavement sections, the models could be used by maintenance managers to determine the increase in maintenance expenditure level required to achieve a specified level of improvement in overall pavement condition.

Since most of the regression models in this study have low R^2 , it is recommended that these models be applied for typical ranges of maintenance expenditure levels. To improve, it is necessary to introduce other factors, such as pavement age and traffic level, as well as to obtain maintenance expenditure data on a wider range. Research is continuing to investigate (1) the effect of pavement age and traffic level on routine maintenance expenditure level and, consequently, on pavement roughness and (2) the effect of routine maintenance expenditure level on pavement service life.

SUMMARY AND CONCLUSIONS

The main objective of this research was to study the effect of routine maintenance expenditure level on pavement roughness. An integrated database for pavement routine maintenance and pavement characteristics for the state highway system in Indiana was developed. Contract section instead of countywide highway section was used as a pavement section unit to develop this database. Results of covariance analysis revealed that the effect of climatic region was significant. Therefore, regression models for the effect of routine maintenance expenditure level on rate of change in pavement roughness were developed, and the climatic region was considered a main factor in these models. The effect of expenditure level was found significant in most of the developed models.

Based on these models, it was concluded that the rate of change in pavement roughness was more in the Northern region, especially at low expenditure levels. Thus, the cost-effectiveness of maintenance activity in the Northern region was higher than that in the Southern region. The results reflect not only the effect of maintenance quality but also the importance of organizing and classifying maintenance records, as noticed in the Northern region. Furthermore, it was found that the effectiveness of patching and sealing was higher than

that of patching alone; and this supports the role of sealing as a preventive maintenance activity.

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The contents of this report reflect the view of the authors, who are responsible for the facts and the accuracy of the data presented herein.

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