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Publication of this paper sponsored by Committee on Maintenance and Operations Management.

Pavement Routine Maintenance Cost Prediction Models

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ABSTRACT

In this paper a methodology is presented for using the available data on pavement routine maintenance from the Indiana Department of Highways (IDOH) to develop models relating the cost of pavement routine maintenance to pavement system characteristics on a network level. The results showed that total pavement routine maintenance costs are affected by traffic level and by climatic zone (weather effect). Furthermore, the analysis of costs of individual activities showed that the extent of patching work (amount of pothole repair that is done after winter) is negatively correlated to the amount of sealing activity that takes place before winter. The implication of this result is that a higher level of service (fewer potholes) may be achieved by increasing sealing activity.

One of the common shortcomings of most current highway maintenance management systems (MMS) is that they are primarily designed for managing available resources (labor, materials, and equipment) and not geared to managing pavement facilities (1). The focus in this paper is on the use of available maintenance management data to provide information that can be directly employed in highway pavement management. In particular, models for pavement routine maintenance costs, which can be effectively used in preparing annual maintenance programs as well as in making decisions about resurfacing and rehabilitation, particularly on a network level, were developed.

As is the case in many other states, the maintenance management system in Indiana is designed for resource management and the necessary data are recorded on an aggregated unit representing a subdistrict. However, other pavement-related information is recorded on the basis of a contract. On the average, a subdistrict may include more than 100 contracts. The nonconformity between the maintenance data and the pavement data makes it difficult to use MMS information effectively in pavement management. For the purpose of this study a system was developed to represent all available data in terms of a highway section that was defined as the part of a highway within a county limit. This system allowed the maximum use of both the MMS data and the pavement management data as a unified information base. The

Indiana state highway system was divided into 820 highway sections.

DATA BASE

The state highway system of Indiana is divided into two categories: Interstate and other state highways (OSH). In this study the two highway systems were further subdivided by geographic location (climatic zone) and by pavement type. Two geographic locations, north and south, were included to reflect the major climatic differences in Indiana (2). The pavement types considered were flexible pavement, rigid pavement, and resurfaced pavement.

For each of the 820 sections, four major groups of information were summarized: traffic, pavement characteristics, climatic zone, and pavement maintenance records. Traffic information included average annual daily traffic (AADT), percentage of trucks, and equivalent axle load (EAL). The EAL was used as the common traffic index to account for different vehicle types and weights (2). Pavement characteristics included pavement type, layer thickness, and age. Climatic zones included geographic areas with similar climate in terms of snowfall, rainfall, temperature difference, and so on. Finally, pavement maintenance records included total production units, total manhours, and types and quantities of materials. Pavement maintenance information was summarized for each highway section by activity and by fiscal year. Pavement routine maintenance activities consisted of the following: shallow patching, deep patching, premix leveling, seal coating, sealing longitudinal cracks and joints, sealing cracks, cutting relief joints, joint and bump burning, and others. The unit costs and different resource consumption rates for these activities were obtained from previous studies (3,4) in addition to available information from IDOH (5-9). An important feature of the study was that it used only those data that are routinely collected by the state.

RESULTS

With network-level management in mind, the information included in the data base was used to develop statistical models that express expected pavement maintenance costs as a function of highway system, pavement type, traffic level, and climatic zone.

Study Unit

As indicated earlier, a highway section was considered as the study unit for this analysis. However, not all highway section data could be used because some of the sections included more than one pavement type (more than one contract). Only those highway sections that had the same pavement type and other characteristics along their entire length were considered.

In Indiana rigid pavement is the major type of pavement on the Interstate system (about 70 percent of total Interstate lane-miles). On the other hand, flexible pavement and resurfaced pavement are the major pavement types on the OSH system (about 90 percent of total OSH lane-miles). In summary, these three categories constitute about 85 percent of the total lane-miles of the state highway system in Indiana. Homogeneous sections were found in the three categories as follows: 26 sections of Interstate rigid, 213 sections of OSH flexible, and 84 sections of OSH resurfaced. The other three categories, Interstate flexible, Interstate resurfaced, and OSH rigid, which represent about 15 percent of the total lane-miles, were found to have a small number of homogeneous sections (five sections for Interstate flexible, eight sections for Interstate resurfaced, and five sections for OSH rigid). Moreover, most of these sections were located in the southern part of the state. These limitations were considered in the statistical analysis.

Total Pavement Maintenance Cost Prediction

Multiple regression analysis was performed to develop pavement maintenance prediction models. Each of the six categories was considered separately and 10 different regression models were tested to fit the data. Five criteria were considered in selecting the best regression model: (a) the general goodness of fit represented by the coefficient of multiple determination (R^2), (b) the general linearity test for the model through the application of the general F-test, (c) the significance of individual coefficients of the model through the t- or F-tests, (d) testing for the presence of autocorrelation problems through the Durbin-Watson test, and (e) the percentage of outliers. For each model within each of the six categories, the five criteria were applied and the best model was specified. An attempt was made during the analysis to have the same model type for the six categories to facilitate comparison of the effects of different factors.

After an intensive search, one model appeared to satisfy all required conditions for the six categories. This model is

$$\log_{10}(TC) = a \log_{10}(\Sigma EAL) + b \log_{10}(\Sigma EAL) \cdot (Z) + c\,(Z) \qquad (1)$$

where

TC = total pavement maintenance cost in dollars per lane-mile per year;
ΣEAL = accumulated equivalent axle load applications (in thousands) during the entire age of the pavement section (number of years since last major activity); and
Z = dummy variable to represent the zone in which the section is located; this variable takes the value of 1 when the pavement section is located in the northern zone of Indiana and the value of 0 if it is located in the southern zone.

The term $\Sigma EAL \cdot Z$ was introduced to measure the effect of the interaction between traffic level and climatic zone.

In almost all cases, and particularly in the type of models presented in Equation 1, the main effect of the variable Z was found to be insignificant. This can be explained by the fact that the dummy variable Z in reality measures the effect of the difference between the two zones and not the direct effect of the climatic zone variable. However, it was found in all cases that the interaction between traffic level and climatic zone was significant. Consequently, the model in Equation 1 was reduced to

$$\log_{10}(TC) = a \log_{10}(\Sigma EAL) + b \log_{10}(\Sigma EAL) \cdot Z \qquad (2)$$

The models for the six categories follow.

For Interstate flexible pavement

$$\log_{10}(TC) = 0.61 \log_{10}(\Sigma EAL) \qquad R^2 = 0.87 \qquad (3)$$

For Interstate rigid pavement

$$\log_{10}(TC) = 0.530 \log_{10}(\Sigma EAL) + 0.032 \log_{10}(\Sigma EAL) \cdot (Z) \quad R^2 = 0.89 \quad (4)$$

For Interstate resurfaced pavement

$$\log_{10}(TC) = 0.590 \log_{10}(\Sigma EAL) \quad R^2 = 0.81 \quad (5)$$

For OSH flexible pavement

$$\log_{10}(TC) = 0.974 \log_{10}(\Sigma EAL) + 0.24 \log_{10}(\Sigma EAL) \cdot (Z) \quad R^2 = 0.85 \quad (6)$$

For OSH rigid pavement

$$\log_{10}(TC) = 0.681 \log_{10}(\Sigma EAL) \quad R^2 = 0.87 \quad (7)$$

For OSH resurfaced pavement

$$\log_{10}(TC) = 0.850 \log_{10}(\Sigma EAL) + 0.040 \log_{10}(\Sigma EAL) \cdot (Z) \quad R^2 = 0.80 \quad (8)$$

A comparison of actual maintenance expenditures and estimated values for Interstate rigid pavement is shown in Figure 1.

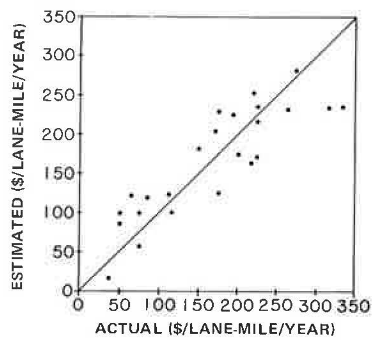

FIGURE 1 Estimated versus actual pavement routine maintenance costs for Interstate rigid pavement.

As may be noticed, Equations 3, 5, and 7 do not include the second term (interaction between traffic level and climatic zone). This is because the number of available sections in the northern zone for the corresponding categories was either small or nonexistent as indicated earlier. It should be noted that the model presented in Equation 4 for Interstate rigid pavement included both jointed reinforced concrete and continuously reinforced concrete pavements. However, the preliminary work on this study, reported elsewhere (10), indicated a higher cost for continuously reinforced concrete sections than for jointed reinforced concrete sections. It was observed that the maintenance cost for continuously reinforced sections was about 15 to 35 percent higher than that for jointed reinforced sections subject to the same traffic level.

In general, it is believed that the choice of the model presented in Equation 2 was appropriate for all categories. It should be mentioned here that, during the analysis, different models were tested for those categories that had enough homogeneous sections (OSH flexible pavement, OSH resurfaced pavement, and Interstate rigid pavement). When an acceptable model had been obtained for these categories, as shown in Equation 2, the general form was simply applied to the other categories for which the available data were not sufficient.

Implications of Total Maintenance Cost Prediction Models

The effect of traffic and its interaction with geographic location can be best demonstrated through the examination of Tables 1-4. In these tables, the average pavement maintenance costs at typical traf-

TABLE 1 Estimated Pavement Routine Maintenance Cost for Typical Traffic Levels on Interstate Flexible, Interstate Resurfaced, and OSH Rigid Pavements in the South

	Estimated Maintenance Cost ($/lane-mile/year)		
Accumulated EAL (10^3)	Interstate Flexible[a]	Interstate Resurfaced[b]	OSH Rigid[c]
1,000	68	59	110
2,000	103	88	177
3,000	132	113	233
4,000	157	133	284
5,000	180	152	330
6,000	202	169	374
7,000	222	186	415
8,000	240	201	456
9,000	258	215	492
10,000	275	229	530

[a] From Equation 3.
[b] From Equation 5.
[c] From Equation 7.

TABLE 2 Estimated Pavement Routine Maintenance Cost for Typical Traffic Levels on Interstate Rigid Pavement

	Estimated Maintenance Cost[a] ($/lane-mile/year)		
Accumulated EAL (10^3)	South	North	Ratio (north to south)
5,000	91	120	1.31
10,000	132	177	1.34
15,000	163	222	1.36
20,000	190	261	1.37
25,000	214	296	1.38
30,000	236	328	1.39
35,000	256	358	1.40
40,000	275	386	1.40
45,000	293	412	1.41
50,000	309	437	1.41

[a] From Equation 4.

TABLE 3 Estimated Pavement Routine Maintenance Cost for Typical Traffic Levels on OSH Flexible Pavement

	Estimated Maintenance Cost[a] ($/lane-mile/year)		
Accumulated EAL (10^3)	South	North	Ratio (north to south)
50	45	50	1.10
100	88	99	1.10
150	131	149	1.14
200	174	198	1.14
250	216	247	1.15
300	258	297	1.15
350	300	346	1.15
400	342	395	1.16
450	383	445	1.16
500	425	494	1.16

[a] From Equation 6.

TABLE 4 Estimated Pavement Routine Maintenance Cost for Typical Traffic Levels on OSH Resurfaced Pavement

Accumulated EAL (10^3)	Estimated Maintenance Cost[a] ($/lane-mile/year) South	North	Ratio (north to south)
100	50	60	1.20
200	90	112	1.24
300	127	160	1.26
400	163	207	1.28
500	196	252	1.29
600	230	297	1.29
700	262	341	1.30
800	293	383	1.31
900	324	426	1.31
1,000	354	468	1.32

[a]From Equation 8.

fic levels (ΣEAL) for appropriate combinations of highway system, pavement type, and climatic zone (north and south) are presented. It is clear that, for the same pavement type and traffic level, the average maintenance cost of the Interstate sections is less than that of the OSH. This is because the Interstate system received a higher rate of major maintenance activities, particularly in the last few years, which may have reduced the need for higher levels of routine maintenance. In general, it can also be expected that maintenance levels differ significantly by pavement type within a particular highway system. For example, in both the Interstate and OSH systems, at the same traffic levels, the highest unit pavement maintenance cost was observed in flexible pavement followed by resurfaced pavements and then rigid pavement. However, an important finding of this analysis was that the effect of traffic level on the difference in maintenance costs is not constant. To illustrate, the Interstate rigid and resurfaced pavements can be considered. At a traffic level of 5 million accumulated EAL, the ratio between maintenance cost of resurfaced pavement and rigid pavement is 1.67, whereas this ratio becomes 1.75 at a traffic level of 10 million accumulated EAL. Similarly, for the OSH system, at traffic levels of 500,000 and 1 million accumulated EAL, the corresponding cost ratios are 2.8 and 3.2, respectively.

An important application of these models is in assessment of the effect of climatic zone and of the interactive effect of traffic level and climatic zone on pavement maintenance cost. The effect of climatic zone on maintenance costs can be easily seen from Equations 4, 6, and 8 for the Interstate rigid pavement, OSH flexible pavement, and OSH resurfaced pavement, respectively. It is clear that, in general, pavement maintenance costs in the northern part are higher than in the southern part. The models, however, not only confirm the geographic difference in maintenance costs, they also point out that this difference increases as the traffic level increases due to interaction effect. For example, for the Interstate rigid pavement, at the relatively low traffic level of 1 million accumulated EAL, the pavement maintenance cost in the northern zone is about 24 percent higher than that in the southern zone; at a higher level of traffic of 45 million accumulated EAL, the northern zone average cost is 40 percent higher than that of the southern zone. The difference between 40 and 24 percent at traffic levels of 1 million and 45 million could be attributed to the interaction effect between traffic level and climatic zone. For the OSH flexible pavement, the ratio between average cost in the northern zone and that in the southern zone ranges from 1.10 at relatively low traffic levels to 1.16 at higher traffic levels. Similarly, for the OSH resurfaced pavement, the corresponding ratios are 1.20 and 1.32, respectively. The main conclusion that can be drawn from these results is that, at higher traffic levels, the effect of climatic zone (weather effects) tends to be more severe. However, the degree of interaction is significantly dependent on pavement type. For example, the unit maintenance cost for OSH flexible pavement in the northern zone is about 16 percent higher than that in the southern zone at a traffic level of 400,000 EAL (Table 3) and about 31 percent for OSH resurfaced pavement at the same traffic level (Table 4). This trend is consistent at all levels of traffic, and it can be concluded that the effect of climatic zone (weather factor) on maintenance cost is more pronounced for resurfaced pavement.

Maintenance Group Cost Prediction Models

The next phase of the study involved the development of cost models for individual maintenance activity groups, namely patching and sealing. The patching group included shallow patching and deep patching. The sealing group included sealing longitudinal cracks and joints and sealing cracks. Models for the

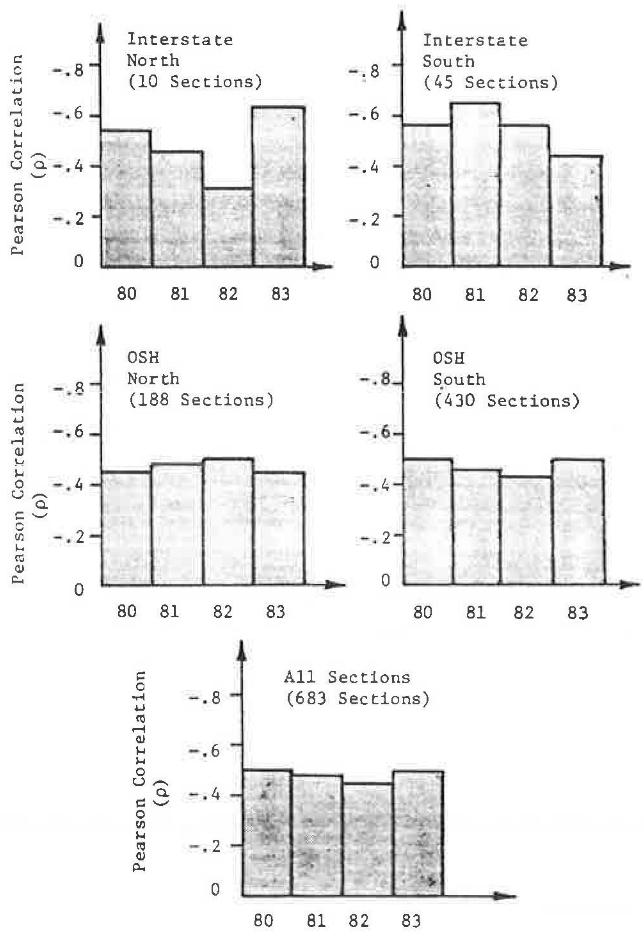

FIGURE 2 Correlation analysis of sealing and patching activities; analysis is based on percentages of total cost allocated to sealing and patching.

prediction of individual maintenance activity group costs can provide a tool for estimating the portions of total maintenance cost that can be attributed to different activity groups such as patching and sealing. In addition, these models can be used to gain insight into the interaction of various maintenance activities under different levels of traffic.

Patching and sealing activities comprise about 85 percent of the total pavement maintenance cost (10) and there is a high correlation between patching and sealing performed in the same fiscal year. Figure 2 shows the results of a detailed correlation analysis performed on the portions of total cost allocated to patching versus those allocated to sealing for different highway categories and fiscal years. A correlation value as high as -0.6 between portions of total cost allocated to sealing and patching was found. The scheduling of different maintenance activities in a fiscal year adds a particular characteristic to the correlation between patching and sealing. This is because sealing activities usually precede patching activities within a fiscal year. Sealing activities take place in the late summer and fall, and patching usually takes place during the spring season after the winter. Although there might be some variation in scheduling of these activities, the majority of sealing and patching jobs occurs during the periods mentioned.

A high correlation between patching and sealing in a fiscal year is a one-way correlation that indicates that the amount of patching done in a year is generally dependent on the extent of sealing performed before the winter. However, sealing activity does not depend on patching activity.

The general type of regression models for patching and sealing follows the form presented in Equation 2. Equations 9-20 are the models developed for sealing and patching for each highway category.

For Interstate flexible pavement

$$PS = 0.185 \cdot \log_{10} (\Sigma EAL) \quad R^2 = 0.87 \tag{9}$$

$$PP = 0.182 \cdot \log_{10} (\Sigma EAL) - 0.670 \cdot PS \quad R^2 = 0.83 \tag{10}$$

where

PS = percentage of total pavement maintenance cost allocated to the sealing group and
PP = percentage of total pavement maintenance cost allocated to the patching group.

For Interstate rigid pavement

$$PS = 0.098 \cdot \log_{10} (\Sigma EAL) - 0.015 \cdot \log_{10} (\Sigma EAL) \cdot Z \quad R^2 = 0.81 \tag{11}$$

$$PP = 0.206 \cdot \log_{10} (\Sigma EAL) - 0.023 \cdot \log_{10} (\Sigma EAL) \cdot Z - 0.998\ PS \quad R^2 = 0.95 \tag{12}$$

For Interstate resurfaced pavement

$$PS = 0.115 \cdot \log_{10} (\Sigma EAL) \quad R^2\ 0.91 \tag{13}$$

$$PP = 0.186 \cdot \log_{10} (\Sigma EAL) - 0.621 \cdot PS \quad R^2 = 0.85 \tag{14}$$

For OSH flexible pavement

$$PS = 0.22 \cdot \log_{10} (\Sigma EAL) - 0.074 \cdot \log_{10} (\Sigma EAL) \cdot Z \quad R^2 = 0.78 \tag{15}$$

$$PP = 0.346 \cdot \log_{10} (\Sigma EAL) + 0.025 \log_{10} (\Sigma EAL) \cdot Z - 0.786\ PS \quad R^2 = 0.89 \tag{16}$$

For OSH rigid pavement

$$PS = 0.1075 \cdot \log_{10} (\Sigma EAL) \quad R^2 = 0.82 \tag{17}$$

$$PP = 0.150 \cdot \log_{10} (\Sigma EAL) - 0.135\ PS \quad R^2 = 0.92 \tag{18}$$

$$PS = 0.196 \cdot \log_{10} (\Sigma EAL) - 0.0617 \cdot \log_{10} (\Sigma EAL) \cdot Z \quad R^2 = 0.81 \tag{19}$$

$$PP = 0.228 \cdot \log_{10} (\Sigma EAL) + 0.011 \cdot \log_{10} (\Sigma EAL) \cdot Z - 0.55 \cdot PS \quad R^2 = 0.84 \tag{20}$$

Implications of Maintenance Group Cost Prediction Models

The models presented in Equations 9-20 are for sealing and patching costs in terms of the percentage of total pavement maintenance cost required at different traffic levels and zones (north and south). As may be seen, sealing prediction models are functions of traffic level (accumulated EAL) and zone (north and south), and patching prediction models are functions of traffic level and zone and also of the level of sealing performed in the same fiscal year. The reason for this is that although patching level is highly correlated with sealing level, sealing activity does not show significant dependence on patching level. This is mainly because most sealing jobs are scheduled before patching jobs within the same fiscal year. In Figures 3-5, graphic presentations of sealing and patching percentages of the total cost at typical traffic levels are shown.

The first implication of Figures 3-5 is that both sealing and patching shares of the total pavement maintenance cost increase as the traffic level increases. This is expected because an increasing traffic level accelerates the pavement distress process, and this, in turn, requires an increased level of pavement maintenance, primarily sealing and

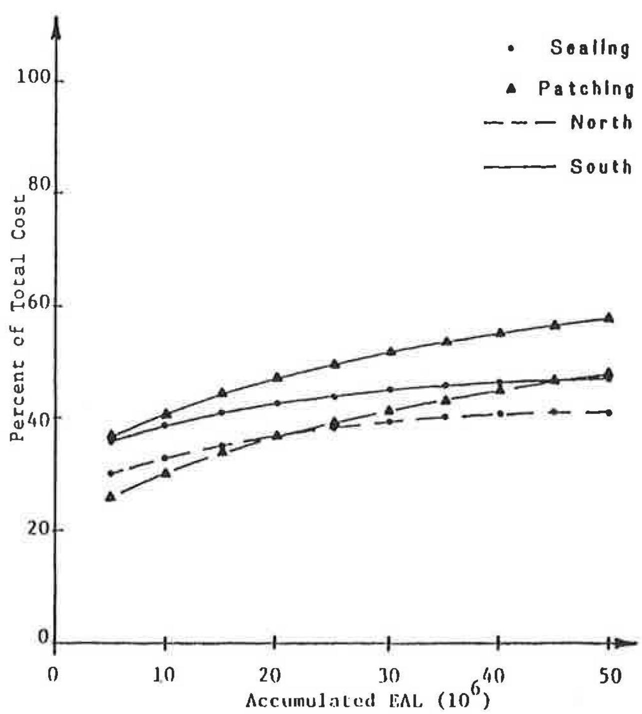

FIGURE 3 Estimated patching and sealing percentages for Interstate rigid pavement.

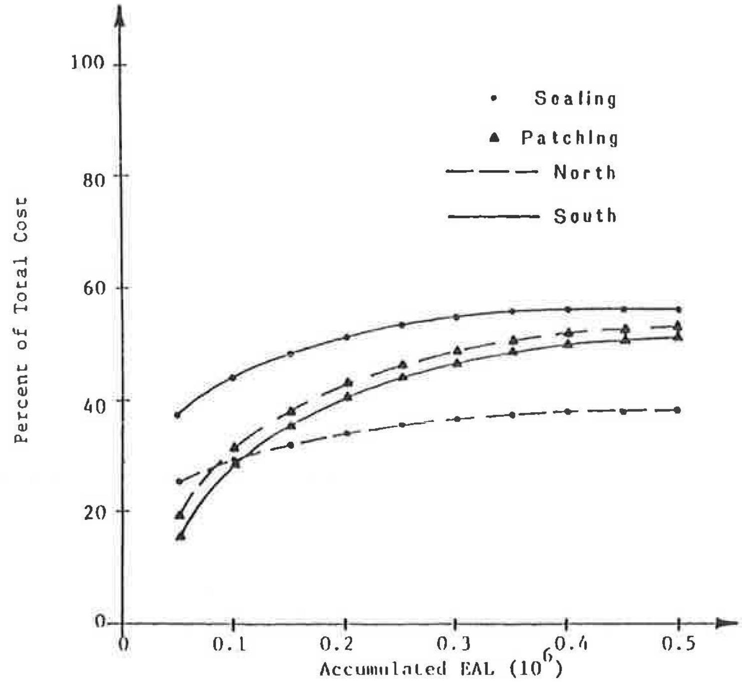

FIGURE 4 Estimated patching and sealing percentages for OSH flexible pavement.

patching. However, the rate of increase in the patching share as traffic level increases is higher than that in sealing.

Second, both rigid and resurfaced pavements show a similar trend in terms of higher patching and sealing shares in the south. This trend, however, was found to be different in the case of flexible pavement (Figure 3) where patching shares are higher in the north than in the south. This could be due to the relatively low level of sealing in the northern part because of the short season available for sealing activity. Because sealing is a type of preventive maintenance, a low level of sealing activity causes a high level of corrective maintenance, patching.

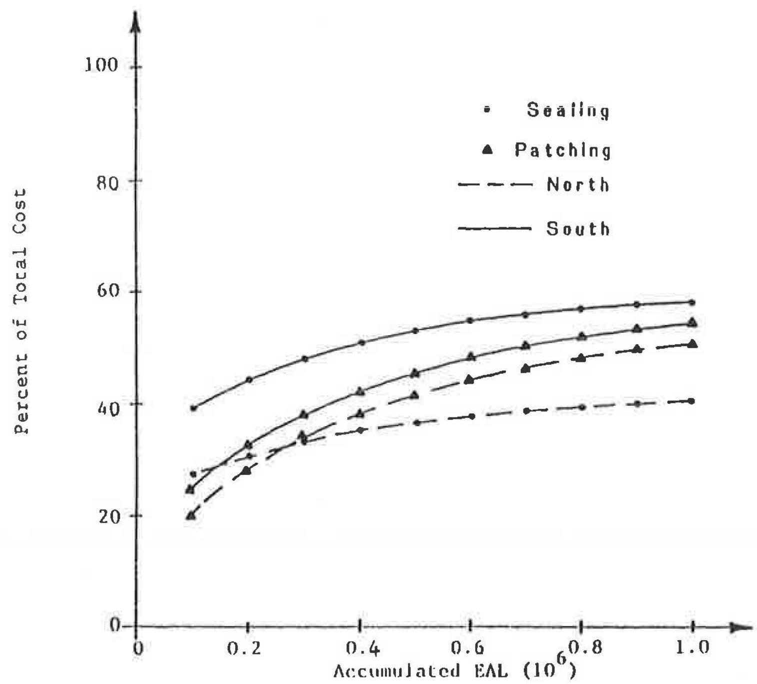

FIGURE 5 Estimated patching and sealing percentages for OSH resurfaced pavement.

CONCLUSIONS

On the basis of the findings of this study, the following major conclusions can be drawn:

1. Total pavement routine maintenance costs for a particular pavement type were found to be significantly affected by traffic level and geographic location (climatic zone). However, it was found that the interaction effect of traffic level and climatic zone (weather factor) is more significant than is that of climatic zone alone.

2. Portions of total cost allocated to major routine maintenance activity groups (sealing and patching) were found to be functions of the same factors. However, it was found that the patching level (amount of patching activities taking place after winter) is negatively affected by the level of sealing (amount of sealing activities taking place before winter). That is, the more sealing of cracks a highway section receives before wintertime, the less pothole patching is required after winter.

ACKNOWLEDGMENT

The work reported in this paper is a part of a Highway Planning and Research Program project funded by the Federal Highway Administration and the Indiana Department of Highways. The assistance of R. Clay Whitmire of the Division of Maintenance of the Indiana Department of Highways is greatly appreciated. The authors are, however, solely responsible for the contents of this paper.

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Publication of this paper sponsored by Committee on Maintenance and Operations Management.