Energy Savings from Increased Preventive Maintenance on Indiana Highways

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In this paper are described the development of trade-off relationships between routine pavement maintenance activities and the application of these relationships in estimating the savings in fuel used in pavement maintenance in Indiana. Two major routine pavement maintenance activities were considered: patching (corrective maintenance) and sealing (preventive maintenance). The results showed that when more sealing was done before winter less patching was required after winter. Different highway classes, pavement types, and geographic locations are taken into consideration. The application example assesses possible cost savings in terms of savings in direct fuel consumption by the maintenance equipment fleet.

The trade-off concept is a central issue in highway system analysis including pavement management systems (PMSs), maintenance management systems (MMSs), and other related areas (*1*). A trade-off relation is a way of determining how much of one alternative has to be sacrificed in order to gain something of another alternative.

In highway programming, trade-off relations can be used to split the available funds among different options at several levels. At the first level, trade-offs may be used to determine the split of total available funds between state roads and other local roads. At the second level, trade-off relations can determine portions of available funds to be allocated to specific highway classes (e.g., Interstates and other state highways). At the third level, trade-offs may be used to distribute available funds between major maintenance activities (federally funded activities) and routine maintenance activities (state-funded activities). Finally, at the fourth level, trade-offs may be used to split available funds among specific maintenance actions. Resurfacing, rehabilitation, and reconstruction are examples of major maintenance actions; and crack sealing, pothole patching, and so on are examples of routine maintenance activities. The last of the four levels is the most significant for a PMS as well as for an MMS because this level deals with the allocation of funds to specific maintenance activities.

The trade-off relations between two routine pavement maintenance activities in Indiana, namely, patching (corrective maintenance) and sealing (preventive maintenance), are discussed in this paper. Total routine pavement maintenance needs are first identified through a set of prediction models; then trade-off relations are developed to indicate the split of total need between patching and sealing activities. Finally, an example is presented to show the use of the trade-off models in assessing possible cost savings in direct fuel consumption.

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DATA BASE

The state highway system of Indiana is divided into two categories: Interstate and other state highways (OSHs). In this study, the two highway systems were further subdivided by geographic location (climatic zones) and pavement type. Two geographic locations, north and south, were included to reflect the major climatic differences in Indiana. The pavement types considered were flexible pavement, rigid pavement, and resurfaced pavement. The units used for data collection and analysis were 820 sections (a section is defined as the portion of a highway within county limits).

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). Pavement characteristics included pavement type, layer thickness, and age. Climatic zones included geographic areas with climates that are similar in terms of snowfall, rainfall, temperature difference, and so on. Finally, pavement maintenance records included total production units, total man-hours, and types and quantities of materials. Pavement maintenance information was summarized for each highway section by activity and by fiscal year. The details of the development of this data base are given elsewhere (*2, 3*). An important feature of the study was that it used only those data that are routinely collected by the Indiana Department of Highways (IDOH).

DESCRIPTION OF MODEL

In Indiana rigid pavement is the major type of pavement on the Interstate system (about 70 percent of total Interstate lane-miles), and flexible pavement and resurfaced pavement are the major pavement types on the OSH system (about 90 percent of total OSH lane-miles). The three categories constitute about 85 percent of the total lane-miles of state highway system in Indiana. Consequently, there are enough homogeneous sections of pavement type and characteristics to give 26 sections of Interstate rigid, 213 sections of OSH flexible, and 84 sections of OSH resurfaced. There were only a limited number of homogeneous sections in other pavement categories (five sections for Interstate flexible, eight sections for Interstate resurfaced, and five sections for OSH rigid), and most of these sections were located in the southern part of the state. These limitations were considered in the statistical analysis (*4–6*).

The general form of the total routine pavement maintenance cost prediction model is given in Equation 1. The model parameters are given in Table 1.

$$\text{Log}_{10}(\text{TC}) = m * \text{Log}_{10}(\Sigma\ \text{EAL}) + n * \text{Log}_{10}(\Sigma\ \text{EAL}) * (Z) \quad (1)$$

where

TC = total pavement maintenance cost in dollars per lane-mile per year;
Σ EAL = accumulated equivalent axle load applications during the entire age of the pavement section (in thousands); and
Z = dummy variable representing the location of the section (north or south).

The term Σ EAL * Z was introduced to measure the effect of the interaction between traffic level and climatic zone.

TABLE 1 PARAMETERS FOR THE ROUTINE PAVEMENT MAINTENANCE COST ESTIMATION MODELS OF EQUATION 1

	Pavement Category					
	Interstate			OSH		
Parameter	Flexible	Rigid	Resurfaced	Flexible	Rigid	Resurfaced
m	0.610	0.530	0.590	0.974	0.681	0.850
n	0.000	0.032	0.000	0.240	0.000	0.040
R^2	0.870	0.890	0.810	0.850	0.870	0.800

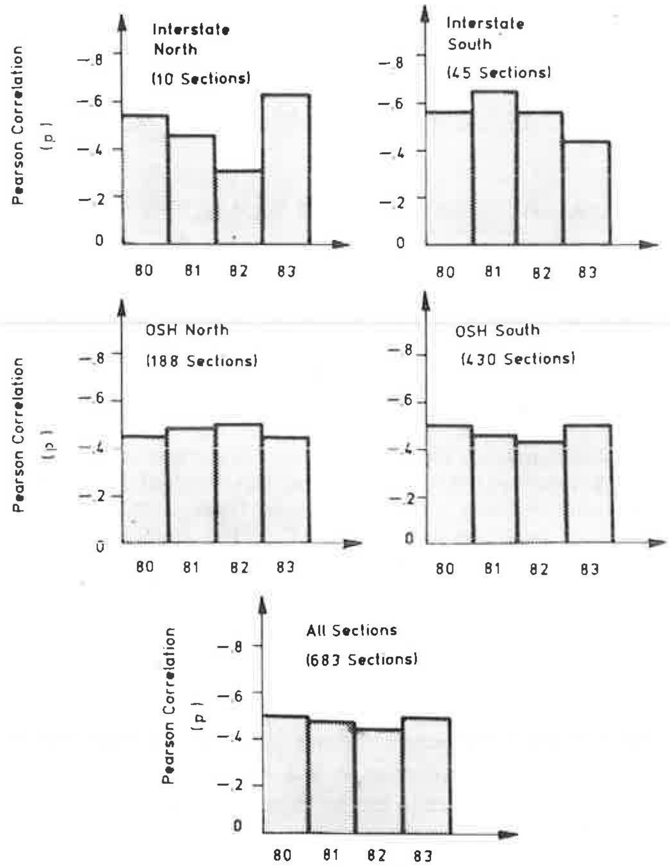

FIGURE 1 Correlation analysis of sealing and patching activities based on percentage of cost allocated to each.

TRADE-OFF RELATIONS BETWEEN PATCHING AND SEALING ACTIVITIES

Cost models were developed 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. Patching and sealing activities account for about 85 percent of the total pavement maintenance cost in Indiana (*3*), and there is a high correlation between patching and sealing performed in the same fiscal year. 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 resulted in a correlation value as high as –0.65, as shown in Figure 1. The scheduling of different maintenance activities in a fiscal year (July-June) adds a particular characteristic to the correlation between patching and sealing. This is because sealing activities usually precede patching activities in a fiscal year. Sealing activities take place in the late summer and fall, and patching usually takes place in the spring. Although there may be some variation in the scheduling of these activities, most sealing and patching jobs are done during the periods mentioned.

The 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, the sealing activity does not depend on the patching activity.

The general regression models for patching and sealing follow the form presented in Equations 2 and 3.

$$\text{PS} = a * \text{Log}_{10}(\Sigma\ \text{EAL}) + b * \text{Log}_{10}(\Sigma\ \text{EAL}) * Z \quad (2)$$

$$\text{PP} = c * \text{Log}_{10}(\Sigma\ \text{EAL}) + d * \text{Log}_{10}(\Sigma\ \text{EAL}) * Z + e * \text{PS} \quad (3)$$

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

The model parameters for the six pavement categories are given in Table 2. The models indicate that, although an increased traffic level requires an increased level of pavement maintenance (patching and sealing), the rate of increase in the share of patching cost as traffic level increases is higher than that in the share of sealing cost. Furthermore, it can be concluded that patching level (amount of patching activity taking place after winter) is negatively affected by the level of sealing (amount of sealing activity taking place before winter). That is, if more cracks are sealed before winter, less patching is required after winter, primarily because of fewer potholes.

TABLE 2 PARAMETERS FOR ESTIMATING PERCENTAGE OF TOTAL COST FOR PATCHING AND SEALING ACTIVITIES (Equations 2 and 3)

		Pavement Category					
		Interstate			OSH		
Activity	Parameter	Flexible	Rigid	Resurfaced	Flexible	Rigid	Resurfaced
Sealing	a	0.185	0.098	0.115	0.220	0.108	0.196
	b	0.000	−0.015	0.000	−0.074	0.000	−0.062
	R^2	0.870	0.810	0.91	0.780	0.820	0.810
Patching	c	0.182	0.206	0.186	0.346	0.150	0.228
	d	0.000	−0.023	0.000	0.025	0.000	0.011
	e	−0.670	−0.998	−0.621	−0.786	−0.135	−0.550
	R^2	0.830	0.950	0.850	0.890	0.920	0.840

EXAMPLE OF USE OF TRADE-OFF MODELS

One of the applications of the trade-off models involves an assessment of cost savings in routine pavement maintenance in terms of direct fuel consumption. In the example given here, the energy cost savings associated with the trade-off between preventive maintenance (sealing) and corrective maintenance (patching) are considered.

Equation 3 established that the extent of patching under a given traffic level is a function of the extent of sealing performed in the same fiscal year. The implication is that a higher level of prewinter preventive maintenance (sealing) can reduce the extent of postwinter corrective or repair maintenance (patching). It was also found that direct fuel consumption (gallons per dollar spent) for sealing group activities is less than for patching group activities (*7, 8*). Consequently, an increased level of sealing activity would not only reduce the need for subsequent patching activities and thus improve overall pavement serviceability, it would also cause savings in direct fuel consumption for routine pavement maintenance.

In this example five scenarios were considered: increasing sealing level by 5, 10, 15, 20, and 25 percent. For each of these scenarios total fuel consumption (gallons per lane-mile per year) was calculated and then compared with the current level of energy consumption in order to estimate the amount of energy saved. With an increase in sealing activity, fuel consumption for sealing would increase. However, the increase in sealing activity would reduce the level of patching, and the corresponding decrease in fuel consumption would more than offset the increase in fuel consumption for the increased level of sealing. The result would be a net savings in fuel consumed by the maintenance equipment fleet. In the following paragraphs a detailed explanation of the procedure for estimating energy savings at different traffic levels is presented.

First, fuel consumption rates in terms of gallons per dollar spent for both patching and sealing groups were developed to avoid the difference in production units of the two groups. A summary of the resulting rates is given in Table 3. It can be seen that energy consumption levels of the patching group are consistently higher than those of the sealing group.

Energy savings were then calculated for all highway categories under different traffic levels. For example, the case of Interstate rigid pavement in the southern zone can be considered. Assuming a traffic level (accumulated EAL) of 20 million, the computations are

TABLE 3 ENERGY CONSUMPTION RATES FOR SEALING AND PATCHING GROUPS

	Energy Consumption Rates (gallons/dollar)			
	South		North	
Highway Category	Patching	Sealing	Patching	Sealing
Interstate, flexible	0.091	0.070	NA	NA
Interstate, rigid	0.094	0.065	0.091	0.063
Interstate, resurfaced	0.096	0.066	NA	NA
OSH, flexible	0.088	0.056	0.096	0.059
OSH, rigid	0.092	0.065	NA	NA
OSH, resurfaced	0.088	0.065	0.089	0.066

Note: NA = not applicable.

1. From Equation 1 with appropriate parameters for Interstate rigid pavement, total pavement maintenance cost = $190.35 per lane-mile per year.
2. From Equation 2 with appropriate parameters for Interstate rigid pavement, percentage allocated to sealing = 42.15 percent.
3. From Equation 3 with appropriate parameters for Interstate rigid pavement, percentage allocated to patching = 46.54 percent.
4. Sealing cost = 0.4215 * $190.35 = $80.23 per lane-mile per year.
5. Patching cost = 0.4654 * $190.35 = $88.58 per lane-mile per year.
6. From Table 3, fuel consumption rates are 0.094 gal per dollar of patching and 0.065 gal per dollar of sealing.

Energy consumed in sealing = 80.23 * 0.065 = 5.22 gal per lane-mile per year. Energy consumed in patching = 88.58 * 0.094 = 8.33 gal per lane-mile per year. Total energy consumption = 13.55 gal per lane-mile per year.

7. For a 15 percent increase in sealing activity, the percentage of total pavement maintenance cost allocated to sealing is 48.47 percent.
8. From Equation 3 with appropriate parameters for Inter-

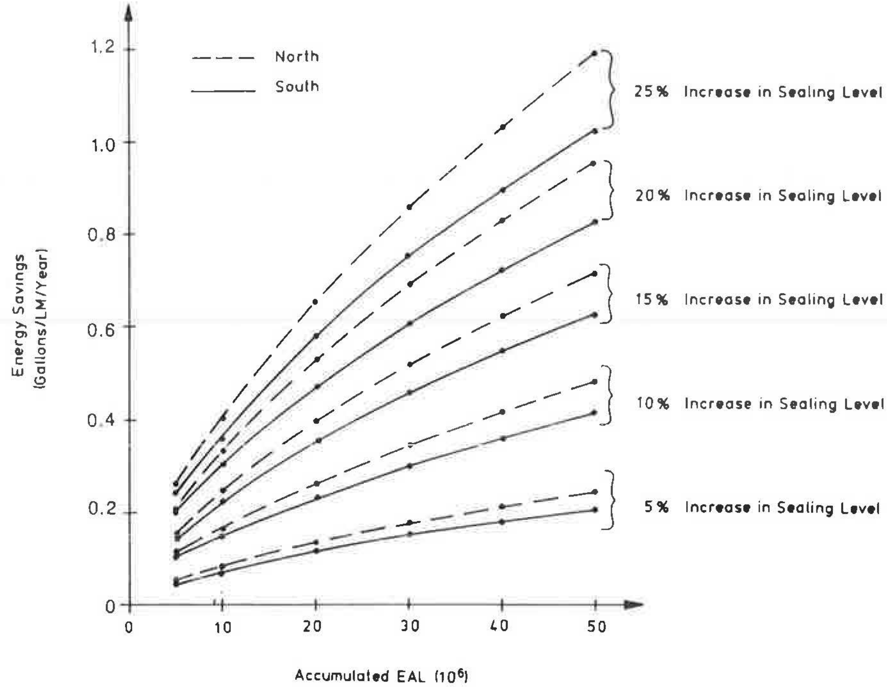

FIGURE 2 Energy savings due to increase in sealing level for Interstate rigid pavement.

state rigid pavement, the corresponding patching percentage is 40.23 percent.

9. Repeating Steps 4 through 6 gives the new total energy consumption as 13.19 gal per lane-mile per year, which results in a savings of 0.35 gal per lane-mile per year due to a 15 percent increase in the current level of sealing.

These computations were repeated for all highway categories for each of the five levels of sealing activity. The resulting savings in fuel consumption for the three major highway categories, Interstate rigid pavement, OSH flexible pavement, and OSH resurfaced pavement, are shown in Figures 2–4, respectively.

The information summarized in Figures 2–4 was then used to estimate expected total energy savings for the IDOH under the five options of increasing sealing level. For example, for Interstate rigid pavement in the north, with an average traffic level of 25 million accumulated EAL, a savings of 0.15 gal per lane-mile per year can be expected with a 5 percent increase in sealing level. This is equivalent to about an 0.85 percent reduction from the current level. Similar computations were done for all other highway categories under the average traffic level and

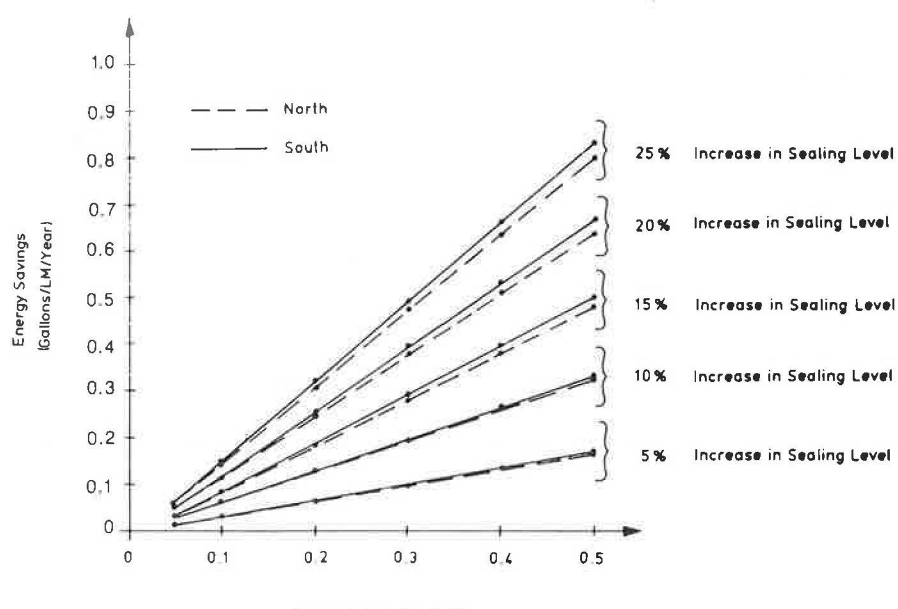

FIGURE 3 Energy savings due to increase in sealing level for OSH flexible pavement.

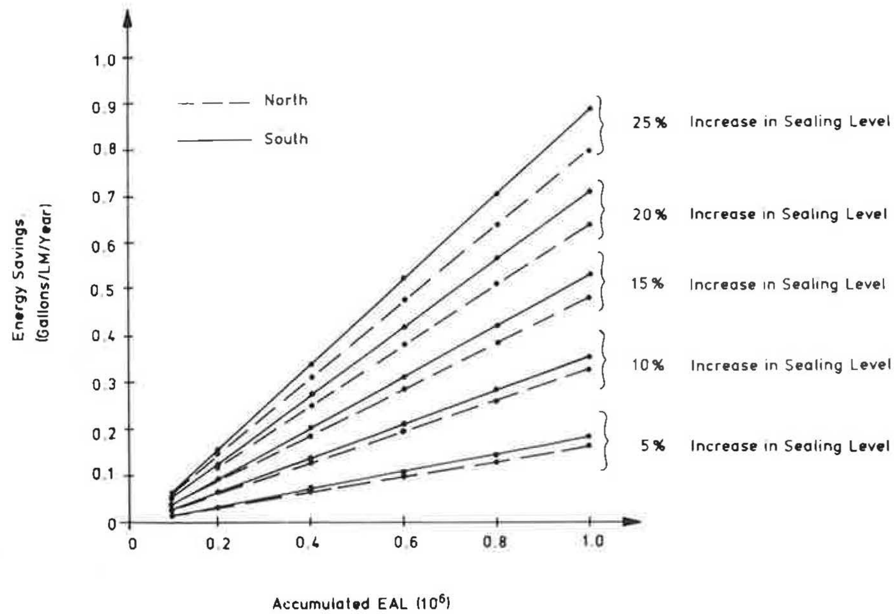

FIGURE 4 Energy savings due to increase in sealing level for OSH resurfaced pavement.

the corresponding percentage reductions in energy consumption. These reduction rates were then weighted by the percentage of total lane-miles of each highway category. The resulting weighted value was taken as the average percentage reduction in energy consumption for the entire state highway system. Under a 5 percent increase in sealing level, it was estimated that the average reduction in energy consumption would be about 0.82 percent. The corresponding reduction rates were 1.64, 2.5, 3.3, and 4.1 percent with an increase in sealing level of 10, 15, 20, and 25 percent, respectively. With an estimated 0.7 million gallons of fuel directly consumed by the equipment fleet in pavement maintenance activities (*8*), the expected savings in motor fuel consumption can be 5,700, 11,500, 17,200, 23,000 and 28,700 gal, respectively, under the five levels of increase in sealing activity.

It should be mentioned here that the energy savings are only the direct benefits of increasing the sealing level. There are also several indirect benefits associated with an increased sealing program. With an increased level of sealing, the amount of patching required is reduced, which indicates a lower level of pavement damage (e.g., potholes). A lower level of pavement damage would improve traffic safety and provide a higher level of service to highway users at less vehicle operating cost.

CONCLUSIONS

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

1. There is a definite trade-off relation between the amount of sealing (preventive routine maintenance) and that of patching (corrective maintenance). This trade-off relation is negative, which indicates that if more sealing is done before winter, less pavement repair (patching) is required after winter.
2. A direct cost savings, attributable to reduction in fuel consumption by the routine maintenance equipment fleet, could be achieved by increasing the level of sealing activity.
3. The developed trade-off relations indicated that the level of service and effectiveness of routine maintenance dollars could be increased through increasing the sealing level, which in turn results in a reduction in required pavement repair (less patching).

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