Abridgment

Estimation of Pavement Routine Maintenance Costs

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ABSTRACT

A methodology is presented for using available state data on traffic, highway system characteristics, and routine pavement maintenance records to develop models relating the cost of routine maintenance to pavement system characteristics. The methodology is applied to sections of the Indiana Interstate system. It is expected that the study results will assist in preparing pavement maintenance program and in making decisions regarding the trade-offs between rehabilitation and routine pavement maintenance.

An effective model to predict routine maintenance costs is an important part of an overall pavement maintenance management system. Two approaches may be used for developing maintenance prediction models. In the first approach, a set of test sections are monitored and data on both maintenance and pavement evaluation items (roughness, deflection, distress, and so forth) are collected and used to develop computer models for maintenance needs (1,2). This approach is primarily used by management at the project level. The second approach uses the available historical records of an agency (e.g., state highway department); this approach is used primarily at the network level.

Historical data could be used to develop average rates of maintenance needs (3) or to develop statistical models such as those presented by Long et al. (4) and McNeil and Hendrickson (5). Normally a time series analysis is applied when a history is available for each section (4); and a cross sectional regression analysis is used when consistent historical data for each section over a period of time are not available. The latter approach was used in this study because only 4 years of information were available from maintenance records.

Two major problems were faced in the present study: the unavailability of historical traffic data and the aggregated nature of the recorded maintenance data. The latter problem was investigated in a study by NCHRP (6) where 11 states were interviewed and 8 of these recorded maintenance data on the basis of highway section (segment), not by mileage post. The problem arises when the highway section (segment) includes more than one pavement type (contract). In that case, it becomes impossible to correlate maintenance expenditure and pavement characteristics. Measures were taken in this study to circumvent these two problems.

Two other issues were resolved before using the state records. To ensure compatibility between the information recorded in the state records and the actual field accomplishment, a field study was performed; and a high level of agreement was found between the jobs recorded and performed (7). Also a correlation analysis of year-to-year expenditures was performed on the 4 years of maintenance information and a high correlation was found (8); this indicated a relatively constant level of service from year to year.

THE DATA BASE

The state highway system of Indiana was divided into 768 highway sections; 62 sections in the Interstate system and 706 sections in the other state highway system. Three types of data were prepared for each section: (a) routine pavement maintenance expenditures; (b) highway section characteristics; and (c) traffic data.

Routine Maintenance Expenditures

Nine pavement maintenance activities were considered for each section: shallow patching; deep patching; premix leveling; seal coating; sealing longitudinal cracks and joints; sealing cracks; cutting relief joints; joint and bump burning; and others. Detailed information on labor, material, and fuel consumption of maintenance equipment was obtained for each of these activities for the last 4 fiscal years (1979-1983). Labor and material unit costs were obtained from the Indiana Department of Highways (DOH) (9,10) and Sharaf et al. (7). Fuel consumption rates and costs were obtained from the results of the field study described by Sharaf et al. (11).

Highway Section Characteristics

Information on section length, section width, pavement type, pavement age, and so forth, is essential for studies of maintenance costs. The highway inventory files of the Indiana DOH were reviewed to obtain the necessary information; however, the accuracy of these data were found to be inadequate for this study. For example, the pavement inventory files include data such as section length, width, and pavement type that were determined by a visual survey from an automobile. Consequently, it was decided to review the original road plans where the actual contract information is recorded. These records were found to be the most accurate source of information for this study. Each highway section was considered individually and the number of contracts within each section was identified. The following information was obtained for each contract:

- Length,
- Width,
- Pavement type and thickness, and
- Pavement age (number of years since contruction or since last major maintenance, such as resurfacing or rehabilitation).

For those highway sections with more than one contract, the information was aggregated based on pavement type. In this way average width, average age, and so forth, were identified for each pavement type within a section.

Traffic Data

To ensure that different vehicle types and weights were fully represented, a common traffic index, 18-kip equivalent single axle load (EAL-18), was used.

The information required to determine the EAL-18 value for a pavement section with known characteristics is the average daily traffic (ADT), the distribution of vehicle types, and the distribution of axle weights by vehicle type. At the time of preparing this paper, the above elements were available only for the Interstate system.

The 1981-1982 Interstate ADT values for each Interstate section were obtained from the most current highway inventory file. The history of ADT values over the past years was obtained from the available continuous station counts. These counts were used to develop average factors for converting the 1981-1982 values to ADT values for the corresponding year. These factors were developed as follows:

$$F_j = \sum_{i=1}^{n} (ADT_{i,j}/ADT_{i,81\text{-}82})/n \qquad (1)$$

where

F_j = ADT factor for the j^{th} year,
n = number of continuous count stations used to compare the j^{th} year count with that of 1981-1982,
$ADT_{i,j}$ = ADT count of the i^{th} station in the j^{th} year, and
$ADT_{i,81-82}$ = ADT count of the i^{th} station in 1981-1982.

To convert the ADT value to EAL-18, the distribution of vehicle types as well as the distribution of axle weights by vehicle type should be known. For this study the EAL-18 value for each vehicle type could be obtained from information available from truck weight studies done by the Indiana DOH (form W-4 is used for that purpose). Thus, factors to convert one vehicle of certain type to its corresponding EAL-18 value were developed for different vehicle types for each year a truck weight study took place in Indiana (1981, 1979, 1977, 1974, 1973, 1972, and 1971). A summary of these factors is shown in Table 1.

As mentioned earlier, a highway section may include more than one contract with different pavement characteristics. Also, a highway section may include portions with different functional classifications. For example, an Interstate highway section may have some portions classified as rural Interstate and other portions classified as urban Interstate. These variations within highway sections were carefully considered when the traffic level in terms of EAL-18 was computed. The general equation for computing cumulative EAL-18 for a highway section is

$$\text{EAL-18} = \sum_{i} \sum_{j} \sum_{k} \sum_{=1}^{n_k} ADT_i * F_{\ell\epsilon n_k} * PT_i * PV_j * EALR_{\ell\epsilon n_{k,j}} \qquad (2)$$

where

EAL-18 = cumulative equivalent axle load applications on a highway section,
ADT_i = 1981-1982 average daily traffic on portions of the highway section belonging to the i^{th} function class,
n_k = age (number of years) of the k^{th} pavement type in the highway section under consideration,
$F_{\ell\epsilon n_k}$ = factor to convert 1981-1982 ADT to the ADT of the ℓ^{th} year of the k^{th} pavement type,
PT_i = percent of trucks in the ADT using portions of the highway section belonging to the i^{th} function class,
PV_j = percent of j^{th} vehicle type in the total number of trucks for the particular year under consideration,
$EALR_{\ell\epsilon n_{k,j}}$ = equivalent axle load ratio used to convert a vehicle of the j^{th} type to its EAL-18 equivalent during the ℓ^{th} year of the k^{th} pavement type (refer to Table 1).

RESULTS OF THE STUDY

A major purpose of this study was to demonstrate how the data available from the Indiana DOH can be used to develop statistical models to predict routine maintenance costs as a function of pavement characteristics without collecting any special purpose data.

Because the maintenance expenditure data are recorded by highway section instead of by contract section, the only data that could be used were those related to highway sections with only one contract. For the Interstate system, three basic pavement types constitute about 87 percent of the total mileage: jointed reinforced concrete (46 percent); continuous reinforced concrete (20 percent); and jointed reinforced concrete resurfaced by hot asphalt emulsion bituminous mixture (21 percent). In this paper, only these three types are considered. The data included 14 highway sections of jointed reinforced concrete, 5 sections of continuous reinforced concrete, and 6 sections of jointed reinforced concrete resurfaced by hot asphalt emulsion mixture.

The statistical analysis included using the least squares method to fit the data. Because there was a

TABLE 1 Average Equivalent Axle Load Factors Used in the Study

	Single Unit Trucks			Tractor Semitrailer Combinations			Semitrailer Trailer			Truck and Trailer		
		EAL[c] Ratio			EAL Ratio			EAL Ratio			EAL Ratio	
Year[a]	Percent[b]	Rigid	Flexible	Percent[b]	Rigid	Flexible	Percent[b]	Rigid	Flexible	Percent[b]	Rigid	Flexible
1981	35.6	0.045	0.043	60.4	1.071	0.681	1.2	0.781	0.828	2.8	0.187	0.199
1979	36.7	0.043	0.040	59.4	1.110	0.708	1.2	1.213	1.262	2.7	0.076	0.065
1977	39.4	0.045	0.042	57.8	1.161	0.740	0.9	1.762	1.766	1.9	0.400	0.290
1974	29.3	0.073	0.070	65.3	1.014	0.662	1.9	1.334	1.328	3.5	0.000[d]	0.000
1973	31.4	0.069	0.064	64.4	1.034	0.677	2.1	1.164	1.207	2.1	0.391	0.333
1972	33.6	0.073	0.062	63.8	0.940	0.620	2.5	1.171	1.211	0.1	0.000	0.000
1971	28.7	0.078	0.070	69.1	0.938	0.593	2.1	1.457	1.469	0.1	0.000	0.000

[a] Years truck weight studies were performed in Indiana.
[b] Percent of all trucks.
[c] Equivalent axle load applications.
[d] Zero means a very small conversion factor.

relatively small number of continuous reinforced concrete sections, the decision was made to pool the data of all concrete sections to develop one model for reinforced concrete pavement. Several model formulations were tried. The model that showed the best fit to the data for reinforced concrete is given in Equation 3.

$$\log_{10}(\text{Cost}) = 0.005 * \text{age} + 0.54\,(\log_{10} \text{EAL}_{\text{acc}}) \qquad (3)$$

where

Cost = total routine pavement maintenance cost per lane mile per year, in 1982-1983 dollars,
age = average age of section (number of years since opened to traffic or since last major maintenance activity), and
EAL_{acc} = accumulated equivalent axle load applications (in thousands).

This model showed a very high R^2 value (coefficient of determination) of 0.98. However, the actual R^2 value may be less than this value because the model was forced to go through the origin.

The number of sections for the resurfaced jointed reinforced concrete was also small. Therefore the number of observations per section was insufficient for statistical analysis, and one model was developed to represent all sections. The corresponding model for resurfaced reinforced concrete is given in Equation 4.

$$\log_{10}(\text{cost}) = 0.032(\text{age}) + 0.57\,(\log_{10} \text{EAL}_{\text{acc}}) \qquad (10)$$

Although the number of sections is relatively small, the models show a good fit as depicted in Figure 1.

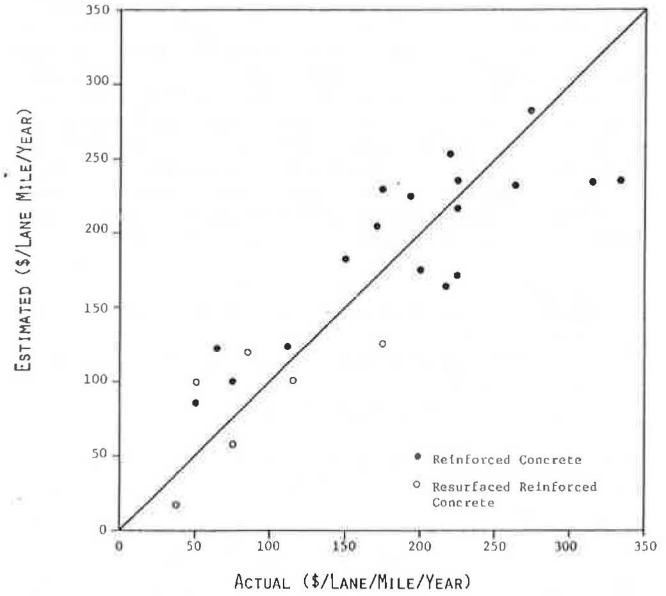

FIGURE 1 Actual Versus Estimated Routine Maintenance Costs.

The basic implication that could be observed from the models presented in Equations 3 and 4 for Interstate reinforced concrete and resurfaced reinforced concrete sections, respectively, is that under similar conditions of pavement age and traffic, resurfaced reinforced concrete sections showed higher maintenance needs than unsurfaced jointed reinforced concrete sections. This is a typical trend experienced in Indiana as well as in several other states.

Reinforced concrete pavement may last for 20 years on the average before resurfacing, whereas a resurfaced section may need a second resurfacing after 5 to 10 years.

CONCLUSIONS

Based on the analysis done in this study, the following conclusions can be drawn.

1. There is a strong correlation between routine pavement maintenance costs, pavement age, and traffic level (accumulated EAL-18).
2. Although the models showed a good fit to the data, the models are considered to be test models used to verify the validity of using the data available from the state without collecting any specialized data.
3. The models of the type developed in the study can be effectively used to evaluate trade-off decisions involving pavement resurfacing and routine maintenance.

Although these conclusions appear to be known, the important point is that the information on which they were based was drawn directly from the available state data records. This should encourage use of such data for developing more comprehensive models that can take into consideration other factors such as pavement structure and weather.

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Road Maintenance Management in the Federal Republic of Germany

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ABSTRACT

An introduction is provided to a system currently being developed to manage maintenance of the road system of the Federal Republic of Germany. The purpose of the management system, which is shown to be based on cost-benefit principles, is to assist both in the decision making and actual operations associated with road maintenance. A conceptual guideline is presented that is intended to contain the most important requirements for such a management system. The guideline addresses general principles; condition survey, evaluation, and selection of maintenance measures as they affect lower, medium, and higher management levels; budget planning and resource allocation; execution of maintenance and new construction; and the creation of a road data bank. The potential savings from implementating a management system for road maintenance are estimated to be substantial and to exceed those accruing from technological advances.

A systematic approach to activities directed toward maintaining roads is a relatively recent objective in the Federal Republic of Germany. These activities, under the collective term of road maintenance, comprise all the categories of repair and rehabilitation. As a starting point, economic studies were made of road construction and agency costs as well as other overall economic evaluations including road user costs. A great deal of data already existed on these subjects. During these economic investigations, it soon became apparent that the decisions involving the type and, above all, the timing of maintenance measures were greatly affected by disparate factors, both from an overall economic and operational viewpoints.

In the meantime developments are taking place in this sphere in other countries; moreover, pressures have been growing through financial stringencies that affect all aspects of road construction and maintenance. Both of these factors contributed to the decision by the Federal Ministry of Transport in 1979 to adopt pavement management as an important focus for road research. Since then, with the Ministry's support, considerable research activity has been directed toward this theme.

What is the primary concern in a planned management system? The relevant operational decisions required in road maintenance must be made on the basis of rational, economic principles. According to a given situation, the goal must be to achieve a desired benefit at the least cost (principle of minimizing costs); alternatively a predetermined cost may have to achieve a maximum benefit (principle of maximizing benefits). Under the economic principle of cost versus benefit some basic operational and economic questions must be considered.

- Who is responsible and how?
- What are the objectives and when will they be accomplished?
- What are the conditions under which a decision will be made?
- What will be the final result?

In connection with these questions, it will be necessary to indicate how decisions can be made in a rational way.

The objectives of a management system fall into three main decision-making categories as follows:

1. Selection of road sections requiring repair, assessment of priority, and the decisons concerning the execution of the repairs. This subject will be discussed by Schoenberger in a paper in this Record.
2. Detailed technical and economic optimization of maintenance measures; that is, select the economically optimal combinations of materials and pavement type, design and strengthening strategies, maintenance strategies, and relevant construction aspects. The most favorable time for executing the work, the optimum site size, and the planned traffic management during the period of repair are also part of this decision.