Guidelines for Management of Chip and Sand Seal Coating Activities in Indiana

IBRAHIM M. MOUAKET, KUMARES C. SINHA, AND THOMAS D. WHITE

Highways are important to the nation's infrastructure: both industry and the public depend on them. Unfortunately, highways are deteriorating at an alarming rate. At the same time, funding for maintenance and repairs is diminishing. Making a case for spending more on maintenance is difficult for several reasons. Logically, performance effectiveness and life-cycle costs should control the decisions about pavement maintenance. Chip and sand seal coating are increasingly used to deal with pavement surface deterioration and to defer capital spending. But the implementation of seal coating is usually left to field managers. Generally, only broad statements guiding such activities are provided. This lack of specific guidance creates problems. The Indiana Department of Transportation (INDOT) wanted to develop, using only currently available data, a guide to help its staff make decisions and to create a consistent practice of seal coating across the state. A life-cycle costing analysis of seal coating is presented. The economic analysis was used to better understand the optimal timing for seal coats. National practice review and an expert opinion survey within INDOT were used to consolidate the state of practice. These sources of information are reviewed, and ways the information was used for developing decision criteria are demonstrated. A decision tree was developed for types of pavement surface distress using data gathered in Indiana. The decision tree suggests a preferred solution and, if funding is a problem, offers a priority ranking for the projects. Recommendations about when to use chip seals and sand seals, and where a choice exists are summarized. The guidelines are designed to meet the needs and constraints of INDOT, but with adjustments they can be used in other jurisdictions.

In the last decade, highway departments have experienced a new working environment characterized by four features:

1. A sharp rise in roadway repair needs due to the aging of the infrastructure (mainly built in the 1960s and 1970s).
2. Declining resources due to the increased competition of public services for the tax dollar and the erosion of the value of money by inflation.
3. The announcement of a new federal policy that stated four expectations or requirements (*1*, p. 1358): (a) the states were to establish systematic procedures for analyzing roadway repair needs; (b) minimum life expectancy of 8 years (5 for special cases approved by FHWA) from newly built, rehabilitated, or reconstructed projects; (c) minimum skid resistance requirements from newly rehabilitated or resurfaced roadways; and (d) the provision of economic analysis in support of requests for funds FHWA. The policy also stated that it would be inappropriate for the states to forfeit maintenance in order to obtain federal funds.
4. The massive retirement of well-trained field staff and their replacement by less-experienced personnel.

This new working environment created pressures to rationalize practices and procedures, establish rules and criteria to guide staff and operations in their decisions, and evaluate the economics of various key maintenance operations within their jurisdiction to create changes that maximize the returns on the dollars spent.

The Indiana Department of Transportation (INDOT) has expressed the desire to investigate, among other things, the practice of chip and sand seal coating, the economics of this practice not only from the agency viewpoint but from that of users as well, and the development of management criteria for unified practice across the state. This paper summarizes the findings and recommended criteria on the chip and sand sealing component of the study.

STUDY APPROACH

Guidance to any maintenance activity such as chip and sand sealing can be stratified into three levels as shown in Figure 1. The highest level of guidance defines whether seal coating is an option for a particular agency and the general circumstances and purposes of its use. The second level refers to the presence of a given set of criteria regarding the attributes of roadway sections that should receive seal coats. The third level refers to the standards to be observed in relation to what materials to use and the procedures to follow, given that seal coating is justified on a certain road section. INDOT has a general statement at the policy level and specifications that cover the areas of materials and procedures; it did not, however, have approved criteria for guiding decisions at the project-management level, and such decisions rested fully with field staff. The department requested that such criteria be developed, taking into consideration the general economics of seal coating to agency and users. Furthermore, two major constraints were imposed:

- The study was to use currently available data (no new data would be collected); and
- The recommended guidelines were to be simple for field staff to use and easy to integrate with INDOT's Roadway Management Project, under development at the time.

The study objective was thus limited to developing management criteria and evaluating the general adequacy of the

I. M. Mouaket, Operations Executive Support, Ministry of Transport, P.O. Box 674, Station A, Downsview, Ontario M3M 1J8 Canada. K. C. Sinha, T. D. White, School of Civil Engineering, Purdue University, West Lafayette, Ind. 47907.

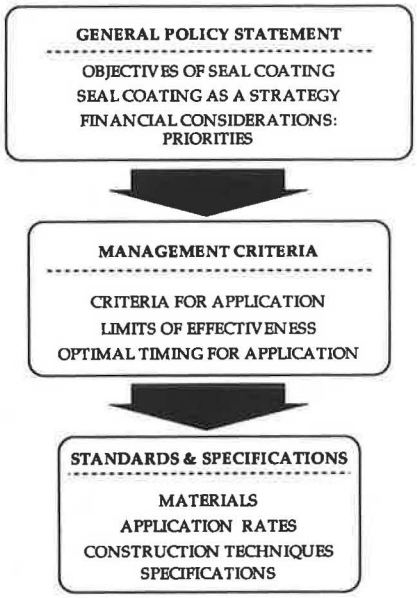


FIGURE 1 Three levels of guidance to seal coating.

policy statement and suggesting modifications as necessary. The study was not for evaluating, revising, or establishing new specifications for materials and construction procedures. To achieve the stated objective, three major areas were identified:

1. A literature review and phone interviews with other state DOTs and research centers;
2. Reviews and evaluations of available data and documents within INDOT, conferences with INDOT staff as required, and an expert opinion survey; and
3. Economic evaluation of seal coating, considering agency and user costs for understanding the general economics of the practice and the optimal timing for seal coating.

The results of these components were grouped, analyzed, evaluated, and synthesized to produce the required guidelines. The results of each component are documented separately in the following.

CHIP AND SAND SEAL COATING AS A PRACTICE

Seal coating is a wide topic. Some seals are applied without aggregates such as fog and construction seals; others are applied with aggregates. When aggregates are used, they can be either mixed in with the emulsions (such as slurry and cape seals) or applied separately (such as chip and sand seals). This study focused on chip and sand seals.

Chip and Sand Seals Defined

Chip and sand sealing involves the application of one or more layers of asphalt-based bituminous material; each layer is immediately followed by the application of a cover of aggregates (in varying thicknesses). These applications are applied to pavements with asphaltic surfaces (flexible and composite—asphalt overlay on rigid), but not on rigid. For chip seals, the cover aggregate is composed of crushed stone, gravel, or slag; for sand seals, the aggregates are either rock screenings or natural sand.

Usage

Chip seals are applied as a blanket cover over oxidized, raveled, and spalled (as in overlaid) pavements; eroded wheelpaths; permeable surfaces; and aging and cracked pavements. They are also often used to restore skid resistance and, more recently, as a strategy to defer capital spending.

Sand seals are generally used to restore a dry, weathered, or oxidized surface; to benefit pavements that have lost some of their matrices; to improve skid resistance; and to reduce raveling.

It is important to point out that both chip and sand seals are surface dressings that affect surface qualities but that have no structural strength to them. Consequently, they cannot, and should not be expected to, treat structural deficiencies or problems.

Factors Affecting Seal Coating Quality

Six major factors affect the ultimate quality of chip seals; they include

- Ambient conditions during and after construction: air and pavement temperature, moisture, and wind;
- Surface preparation before seal coating: whether the pavement is clean and dry or whether it is open, flushing, patched, or shaded;
- Materials: type and grade of asphalt; method of storing and handling of asphalt; type, size, and condition of cover aggregates; and application rates;
- Equipment: distributor spray bar height, nozzle orientation with respect to the bar, spray tip size and cleanliness, and pump condition; spreader gates and auger roller condition.
- Operation coordination: preapplication preparation; control of material application and rolling during the operation; traffic control and brooming of excess aggregates after the rolling; and
- Postsealing inspections: checking of aggregate embedment into asphalt; application of fog seal to compensate for low asphalt application rate or correction of situations in which there is too much asphalt; and reinforcement of weight restrictions.

The cost-effectiveness of any activity depends highly on the quality of materials and workmanship. In the economic evaluation of seal coating, it was assumed that appropriate quality controls were applied and the seals were properly done.

Major Issues

There are many issues related to seal coats; these issues can be grouped under three categories: policy, project manage-

ment, and materials and workmanship. Each will be discussed separately.

Policy

Policy-related issues concern the principles that should guide the use of seal coating; the superiority of chip or sand seals; situations in which seal coating is cost-effective; and the use of seal coating on high-volume roads and high-truck-volume roads. A summary of the findings follows.

Seal coating is invariably used on roads with asphaltic surfaces but not on concrete. Because of the relatively thicker seal layer, some consider chip seals to be superior to sand seals. Others argue that both seals are useful and have their own applications; hence, the question of which seal is superior is irrelevant. Instead, the question should address when to use which. Seal coating is normally applied on low-volume roads and on roads with a low percentage of trucks. However, some agencies have used it on high-volume roads with very strict traffic controls attached, both during and after construction. Objections cited against the use of seal coats on high-volume roads include the problem of flying stones (and the damage they do to other vehicles) and public objections to closing the road for days to allow for proper curing. Two innovations were reported to have a potentially significant impact on resolving these issues: the sandwich seal (French Dressing) and the application of emulsion breaking agents (*2*). The sandwich seal calls for first applying a dry layer of aggregates on the old surface and rolling it with light steel rollers, next spraying the emulsion, and finally applying a layer of dry aggregates and rolling it with pneumatic rollers. When the emulsion-breaking agents are sprayed on the dry aggregate, the breaking agent reacts with the emulsion and causes it to break much faster than it would without the agent. With regard to truck traffic, conflicting messages are found: some claim the heavy weight of trucks can create severe damage in the thin seal coat layer; others claim that, once the seal coat cures, the weight does not matter—instead, the volume of traffic does.

Project Management

Issues related to project management include items such as what performance indicators to use for seal coating purposes, conditions or criteria to use for identifying candidate projects for seal coating purposes, which type of projects should receive priority when funds are short, and how to measure the cost-effectiveness of seal coating for a given situation.

Little information was found in the literature on this area. Telephone inquiries with a number of states were essential. Most states contacted do not currently have any approved and documented guidelines in this area. However, several agencies indicated that their organizations were working to identify such criteria. Two studies were found that offered a limited number of published criteria. A study in Minnesota (*3*) offered some rules based on surface condition ratings of certain attributes. Washington DOT (*4*) documented recommendations with respect to traffic level [annual average daily traffic (AADT) less than 5,000] and percentage composition of heavy commercial vehicles (trucks made up less than 15 percent for AADT more than 2,000).

Material and Workmanship

The group of issues related to materials and workmanship concerns the best type of asphaltic materials to use and at what rate; the ideal size of aggregates; whether modified asphalts should be used; when to use cationic or anionic emulsions; the relative superiority of cementing materials such as RS-2, AE-90, and AE-150; and so on. As discussed earlier, this group lies within the scope of specifications provision; INDOT's specifications address these matters and, hence, were not of concern to this study.

PAVEMENT PERFORMANCE DATA AVAILABLE

A review of INDOT's files revealed that the department had records of the following pavement performance indicators:

- Road roughness numbers (RN). These measurements are obtained in the field by a PCA Roadmeter. RN measures the square of the number of ⅛-in. displacements of the autobody from the axle per mile.
- Pavement serviceability index (PSI). This index is computed from roughness data using a calibrated equation developed by INDOT's research division.
- Pavement serviceability rating (PSR). This is a visual average rating of the pavement condition based on a windshield survey. It is a combined measure of the comfort of the ride and the pavement surface distress.
- Skid resistance measurements (SkidN). These measures are obtained in the field in accordance with ASTM Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire (E274).

Of the four categories, RN data were found to be the most reliable. Moreover, RN and PSI were interchangeable because of the established mathematical relationship. PSI was used for the economic analysis because the available user cost information was based on road geometrics and condition measured in PSI. In the recommended guidelines, RN was used because it is the actual measured quantity in the field.

CHIP AND SAND SEALING IN INDIANA

To understand the state of practice of seal coating in Indiana, several methods were used; findings from each are documented.

Review of Historical Data

The period between 1984 and 1987 was chosen as a basis for studying the extent and variety of seal coating practice across Indiana. The annual INDOT road life records and surface change reports (*5*) contained information on the extent of the highway network and the major surface activities undertaken

in a given year. INDOT seal-coated some 2,940 mi during the 3-year study period, averaging about 1,000 mi/year. This represents about a ninth of the 8,860 mi of rural roads, which is the candidate population for seal coating (*6*). Seal coating in Indiana during the study period split 50-50 between sand and chip seals. Most districts were observed to use both, but four out of six districts concentrated on one type. Even if two districts favored a given seal, there were variances from district to district because, during the study period, Indiana had four types of single and double, chip and sand seal combinations (see Table 1); INDOT has since revised the types to seven.

Staff Interviews and Meetings

Discussions with INDOT staff indicated that seal coating was normally used on low-volume roads, but exceptions were reported from the northern part of the state, where heavy traffic is normal. Seal coating was used to defer capital spending even on high-volume roads (as high as 13,000 AADT). When seal coating is applied on high-volume roads, strict construction and traffic controls are enforced. INDOT staff opinions were that seal coats last about 4 years in service for medium- to low-volume roads and that perhaps a maximum of 4 seal coats are possible before rehabilitation work is required. It was the consensus among field engineers that the overall traffic level, not truck traffic, is the determining factor for the life of the seal coat.

Expert Opinion Survey

A questionnaire survey was mailed to 14 INDOT staff members in the districts and central office. Ten complete responses (five from districts and five from central office) and one partially complete response were received and used in the final analysis. The survey indicated that the majority (90 percent) of respondents think that chip seals are effective and should continue to be used; a much lower number (64 percent) hold the same opinion about sand seals. In deciding to use chip seals, the primary factors considered are pavement condition and traffic; roughness and age are considered secondary factors. For sand seals, age, roughness, and traffic are the main decision factors. The trigger levels (roughness, for example) vary by surface type. The average life expectancy of sand seals was generally reported to be lower than that for chip seals. Life expectancies of chip and sand seals were observed to vary depending on the road's condition at the time of treatment application. This information proved valuable in the economic evaluation phase because the subsequent observational data did not yield reliable life expectancies.

TABLE 1 TYPES OF SEAL COATS USED IN INDIANA DURING STUDY PERIOD

TYPE	DESCRIPTION	COVER AGGREGATE SIZE NO.	RATE OF APPLICATION PER SQUARE YARD	
			AGGREGATE Pounds	BITUMINOUS MATERIALS Gallons at 60 deg. F
I	SINGLE APPLICATION	Boiler Slag, 11, 12, 13	15 - 25	0.20 - 0.40
II	FIRST APPLICATION	11	15 - 20	0.25 - 0.35
	SECOND APPLICATION	12, 13	15 - 25	0.20 - 0.30
III	FIRST APPLICATION	8, 9	25 - 40	0.35 - 0.50
	SECOND APPLICATION	11	10 - 20	0.25 - 0.40
IV	SINGLE APPLICATION	17, 14	10 - 25	0.10 - 0.25

ECONOMIC EVALUATION OF SEAL COATING

In economic analysis, it is assumed that the road has been built and the issue is whether to seal coat or not. The construction cost of the pavement was, therefore, considered sunk cost and hence excluded. Agency costs included in the analysis are those of maintenance, seal coating, and rehabilitating at the end of the life cycle. User vehicle operating costs were also included using the latest 1982 FHWA update study (*7*).

Economic Evaluation Framework

Seal coating is generally associated more with pavement distress than with roughness. Because of the completeness and greater reliability of the RN data and the availability of user costs in terms of PSI (which is highly correlated with RN), it was decided to use roughness data for the economic evaluation.

The underlying logic of the economic evaluation can be illustrated with the aid of Figure 2. The figure demonstrates that the agency maintenance and user operating costs increase with roughness. As shown, there is a decrease in agency and user costs when seal coating is applied. Subsequently these costs continue increasing until the end of the pavement's life cycle; the cycle was assumed to repeat perpetually. The maintenance costs used in the evaluation were correlated to pavement age and condition using Indiana's observational data sample (with RN changed into PSI). User costs were available from the source by road condition (measured in PSI), geometrics, and attributes. If the pavement received two or more seal costs, similar cost profiles were assumed and the total cycle was again assumed to repeat itself in perpetuity. The impact of seal coating on roughness was found to vary with the pavement's condition at the time of seal coating. This finding was confirmed in other studies (*8*).

Pavement performance was first predicted for every year and strategy assumed; maintenance, agency, and user costs were then assigned according to the condition experienced. All costs were finally discounted to the present worth using 6 percent interest rate and the equivalent uniform annual cost (in perpetuity) was computed.

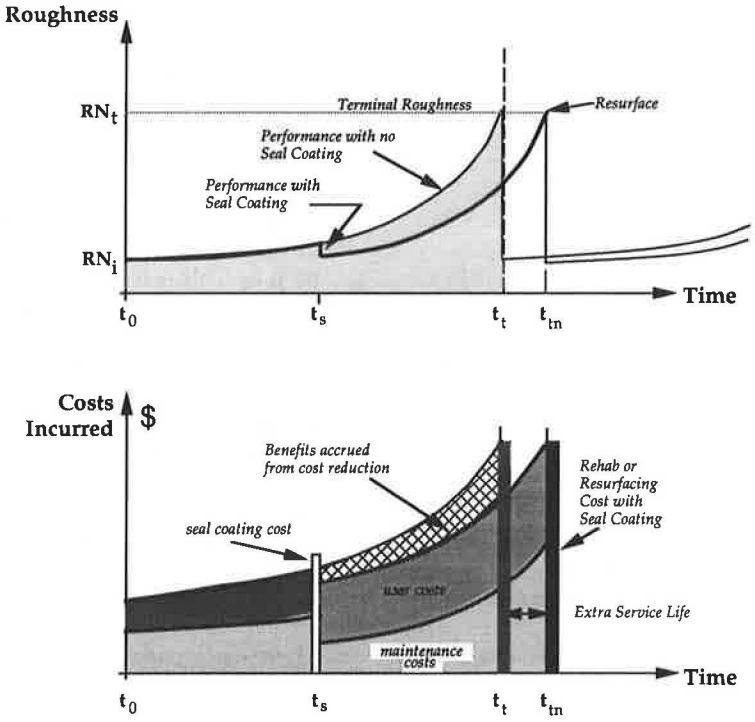


FIGURE 2 Agency and user cost profiles for seal coating strategy.

Deriving Basic Functions for Seal Coating Impacts in Indiana

In order to derive the required functions for carrying out the economic evaluation, a stratified two-stage sample was picked from 12 subdistricts. These data were used to derive three main functions:

1. The first function related PSI (before treatment) of the road sections (with AADT < 3,000) that have only been seal-coated to their current age (see Figure 3).

2. The second function related the PSI jump due to seal coating to the original PSI before seal coating. Due to their quality, the data for this function displayed significant noise (accumulation of errors attributable to items other than the effects of the parameter of interest); consequently, it was decided to carry out the analysis for the most optimistic scenario by assuming the maximum impact experienced. For initial PSI (value before action was taken) greater than 1.6, the jump was estimated as

$$\text{PSI jump} = 0.41\ (\text{PSI} - 1.6) \qquad (= \text{zero, PSI} \leq 1.6)$$

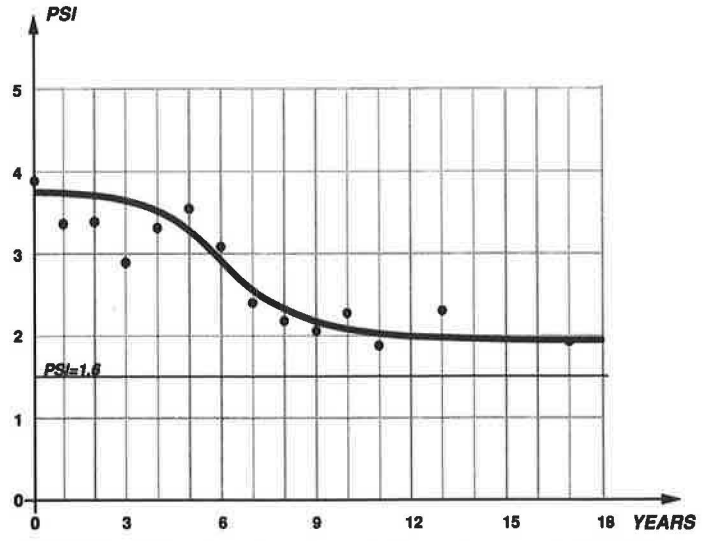


FIGURE 3 PSI as function of age for low-volume roads (AADT < 3,000; points plotted represent means; total observations = 22).

3. The third function related the routine maintenance cost to age of pavement (as shown in Figure 4).

Life expectancies of seal coats were extracted from the expert opinion survey, as mentioned earlier.

Analysis Results

Four scenarios were analyzed in this study, as shown in Figure 5. Each scenario (or strategy) was analyzed for four levels of AADT (2,500, 1,500, 1,000, and 500) and varying PSI trigger levels for action (varying from 3.5 to 2.5 PSI). The results (*9*) are discussed in the following.

Agency Costs

Theoretically, agency cost is expected to vary with traffic and road condition. However, as demonstrated in Figure 4, maintenance curve used is almost flat within the first 8 to 9 years. Moreover, within small ranges of traffic variation (such as the relatively low volumes tested), agency cost is not expected to be highly sensitive to AADT variations, particularly after discounting to present worth. The variation in agency cost can be expected to vary with one of two factors: variation in PSI action trigger level and variation in the number of seal coats applied in a lifetime. As calculated, agency cost tended to be insensitive to variation in PSI trigger levels. For example, agency cost dropped marginally (less than 2 percent) as the PSI trigger level was dropped within the 3.5 to 3.0 range, but is was insignificant (less than 0.5 percent) when the PSI range was less than 3.0.

As expected, agency cost tended to decrease with the number of seal coats but at lower pace. For example, without seal coating, the annual agency cost per lane mile was about $2,607, in perpetuity; with one seal coat (at PSI 3.00), it was $1,652; with two seal coats (at PSI 3.00), $1,187; and with four seal coats (at PSI 3.00), $744.

User Costs

User costs are expected to change with the variation of the same factors above plus the usage levels (AADT). As calculated, user costs tended to drop significantly after one seal coat but rose with the application of two or more seal coats. For example, for PSI = 3.00 and AADT = 2,500, user costs with no seal coating strategy were on the order of $82,208; with one seal coat, $80,153; with two seal coats, $81,816; and with four seal coats, $83,134. Hence, seal coating four times was estimated to cost the users more than not seal coating at all; the magnitude and rate of this rise after one seal coat varied by AADT. The explanation is perhaps that because applying more seal coats preserves mediocre condition when compared with resurfacing after one seal coat.

User costs tended to increase with the delay of seal coating action (action PSI level was lowered). The increase was very slow in general, about 1 percent. And user costs tended to drop directly with AADT level. For example, for assuming PSI = 3.0 as a trigger level and seal coating twice in a lifetime, user costs were estimated at about $81,816 for AADT = 2,500; $49,089 for AADT = 1,500; $32,726 for AADT = 1,000; and $16,363 for AADT = 500.

Total Costs

The variation of the total cost depends on the variation in its components. However, because the component costs varied inconsistently, the total costs tended to vary in the same inconsistency. As the action PSI trigger point is lowered, the increase in user cost was much higher than the marginal gains in agency cost savings. Hence, for this variable, total costs tended to follow user costs. Stated inversely, the better the surface condition at the time of application of the seal coat, the greater the overall benefits.

The total cost (agency plus user costs) tended to drop after one seal coat but increased with the increase in the number of seal coating applications for roads with AADT ≥ 1,000.

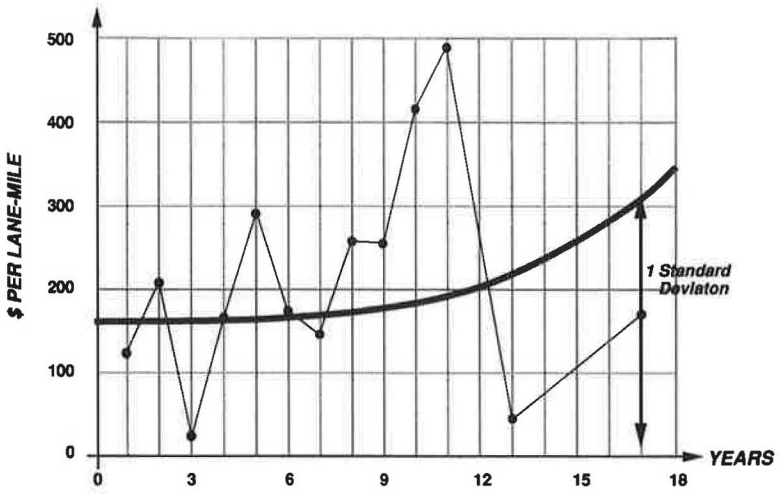


FIGURE 4 Only-basic routine maintenance cost as function of age (points plotted represent means; total observations = 22).

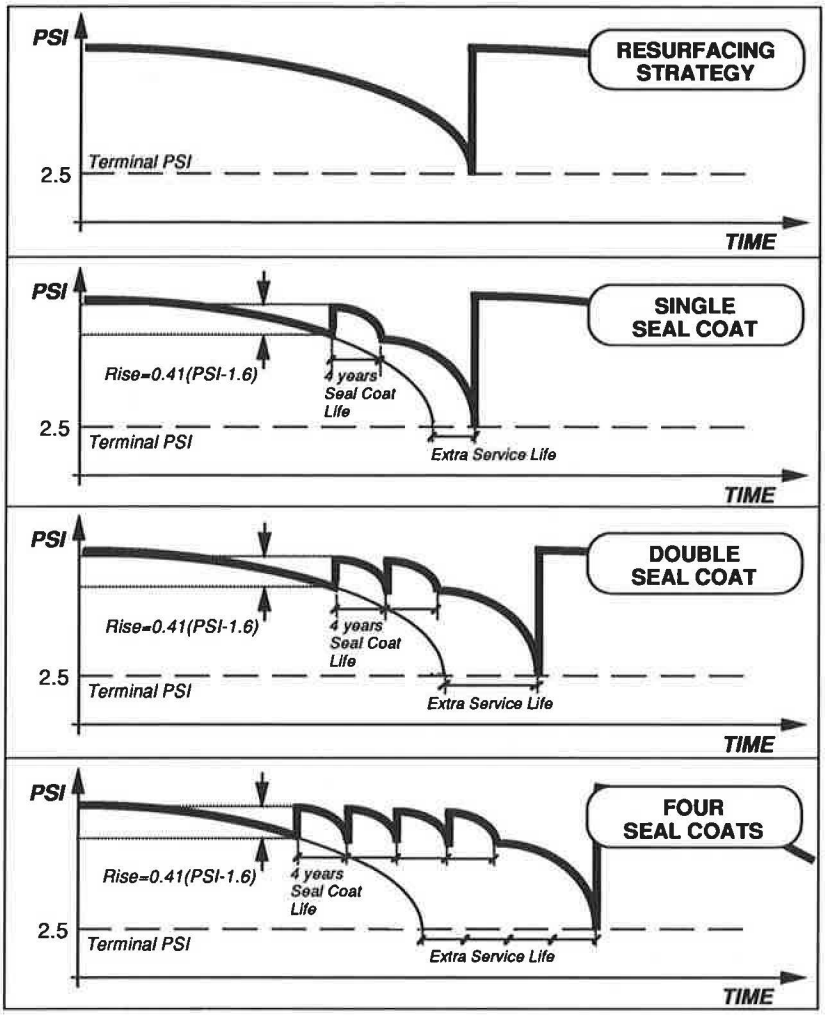


FIGURE 5 Alternative maintenance strategies considered.

For roads with AADT < 1,000, the total cost continued to decrease. This suggests that for very low volume roads, seal coating is a cost-effective solution and rehabilitation should be done only when absolutely necessary. For roads with higher traffic volume, seal coating once, perhaps twice as a maximum, was more desirable. Because agency cost did not vary within any given strategy, user costs were the determinants of trends with respect to total cost variation with traffic.

In summary, the economics of seal coating suggest several management policy lessons and directions:

- Seal coating does yield overall savings and hence should be retained as a legitimate option;
- The earlier the seal coating, the better (as long as it is not done too early);
- "The more seal coats, the better" is true for very low traffic (AADT ≤ 1,000) but not necessarily for roads with more significant traffic (AADT > 1,000).
- Taking into account both economic and practical considerations for timing, seal coating of higher traffic volumes (AADT > 1,000) would be ideally desirable at PSI = 3.0, whereas that for lower traffic volumes, at PSI = 2.7 (at 2.5, resurfacing would be required);
- When seal coating is to be used for buying time for the resurfacing option, it should not be used on roads with PSI ≤ 2.0; and
- Cost-effectiveness is dependent on one's perspective: agency, user, or total cost perspective (in this study, the total cost was used as a basis for evaluating cost-effectiveness).

POLICY GUIDELINES

This section summarizes the policy guidelines based on the findings of the research. The recommended guidelines can be grouped under three headings: general policy statement, specific management criteria, and guidelines on specific issues. A discussion of each follows.

General Policy Statement

Seal coating should be used on low- or medium-volume roads in the amounts necessary to correct surface deficiencies (but not structural) or to prevent the development of more-serious structural problems. Specifically,

- Seal coating may normally be applied on flexible or composite (asphalt overlay on PCC) pavements carrying 2,500 AADT or less; application to higher-volume roads can be made as long as adequate traffic controls are put in place to ensure sufficient time for curing;
- Seal coating should be considered on roads exhibiting slipperiness, bleeding, oxidization, raveling, spalling (composite pavements), erosion (dusting), or a permeable surface; and
- Seal coating may also be considered as an alternative measure to delay capital spending on roads with any traffic volume level.

Management Criteria

The recommended management criteria take the form of a decision tree. The tree, however, not only specifies the situations for which seal coating is the preferred solution from an engineering viewpoint, but it also provides priority rankings in case of fund shortages

Definitions of Seal Coating Priority Groups

In case of fund shortages, roadway sections that meet the low usage and bituminous surface criteria set in the general policy statement fall into one of four groupings based on these criteria:

- Priority Group 1—This group includes roads that need seal coating for safety reasons (SkidN < 30) and are subjected to significant usage (AADT > 1,000); roads that are in fair structural condition but exhibit aging signs [oxidation and mild alligator cracking (*10*)]; relatively new roads that have surface mix deficiencies and are subjected to high usage (AADT > 1,000); and roads that are raveling or showing signs of erosion or a permeable surface.
- Priority Group 2—This group includes roads that need seal coating for safety reasons (SkidN < 30) and are subjected to low usage (AADT < 1,000) and high-usage roads (AADT > 1,000) experiencing roughness confined to the surface but no structural distress.
- Priority Group 3—This group includes roads that cannot be resurfaced because of a shortage of funds for at least 2 to 2.5 years hence and roads that have a low level of serviceability (PSR = 2.0) but are not scheduled for capital work in the near future.
- Priority Group 4—This group includes roads that have roughness problems only (that is, acceptable PSR and no skid problems); roads that are suffering from structural problems and surface problems; and roads with curbed sections.

Decision Tree

A decision tree incorporating these criteria is shown in Figure 6. It can be used as a guide for interpreting the policy in management decisions relating to seal coating. The decision criteria were selected with consideration of the currently available information in INDOT: skid numbers, roughness numbers, age, and present serviceability ratings (measures of pavement distress). Using the pertinent information on a given section and following the appropriate path leads to a recommended technical solution and programming priority under financial constraints.

Ideally, these four groups of criteria will be augmented with detailed surface attributes and distress-related indicators or measures, when such parameters become available. The decision tree must be expanded to accommodate such new criteria.

Guidelines on Specific Issues

Guidance is offered on the applicability of seal coating for three specific issues.

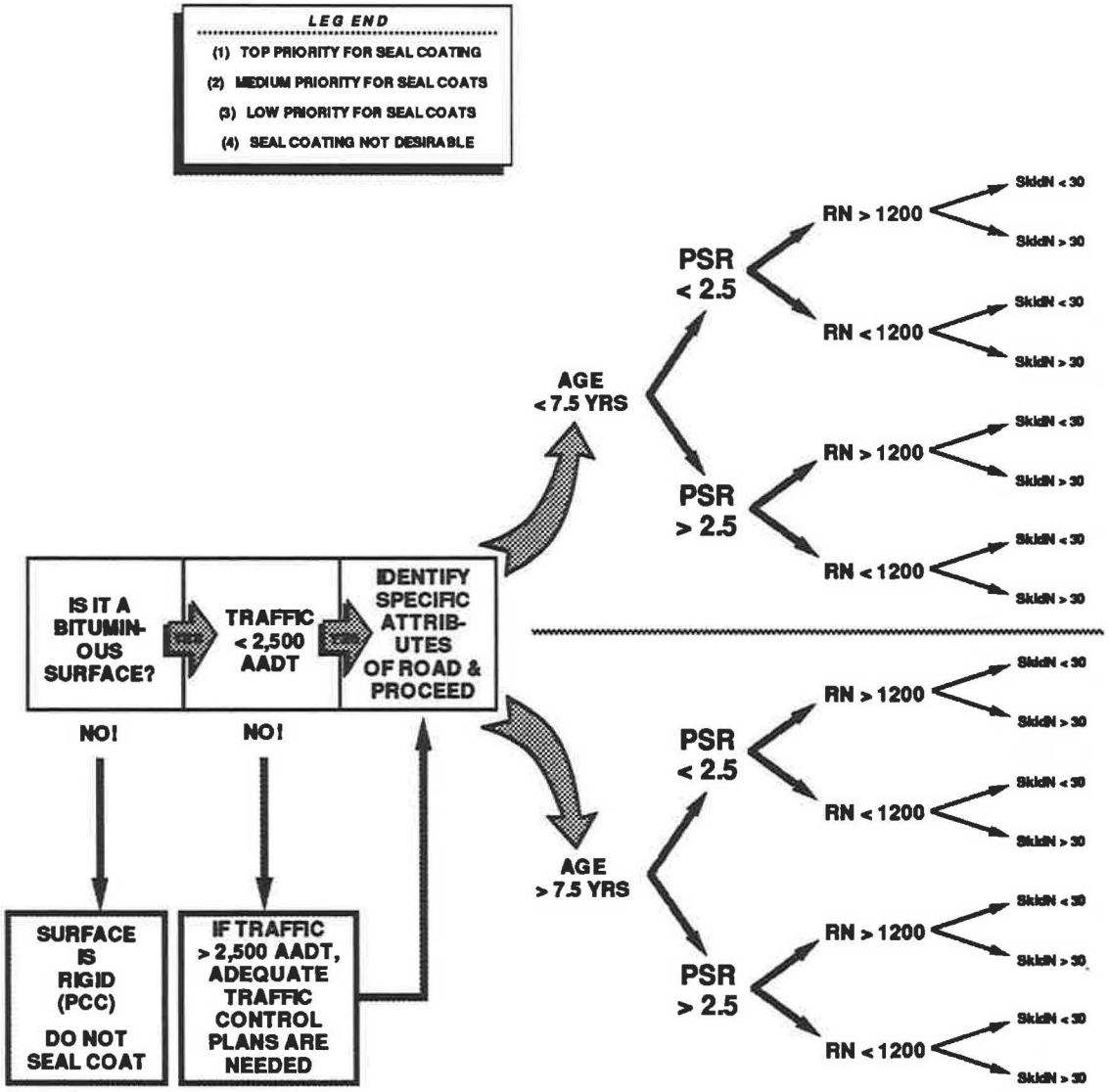
Sand or Chip Seal

Some rules for when chip seals and sand seals should be applied follow.

- Sand seals are more cost-effective for use on oxidized pavement; chip seals are more effective than sand seals on cracked pavement.
- Chip seals tend to have more bleeding problems than sand seals. Hence, for bleeding pavements, sand could be more effectively employed to bloat excess asphalt.
- If the source of poor skid resistance is the loss of fine matrix around the coarse aggregates, then sand sealing would be the more cost-effective.
- Chip seals are more effective than sand seals on spalled surfaces (overlaid pavements).
- Severe raveling or cracking can be treated more effectively by chip seals than by sand seals.
- Because sand seals are cheaper then chip seals and both seals bond together effectively, sand seals could be an option for the first seal during double sealing.
- In making the final choice of sand or chip seal, the availability and economics of quality materials would have to be considered.

Seal Coating on High-Volume Roads

The recommended general policy direction did not exclude the use of seal coating on high-volume roads provided adequate traffic controls were put in place to ensure adequate curing. The time required for curing depends on many factors, including the type of binder used and ambient conditions. Generally, two objections have been given to the use of seal coats on high-volume roads: the long closures of the roads to traffic and the damage created by flying stones. These objections may be addressed by the use of smaller, precoated chips. The amount of flying chips would then be reduced and, hence, the damage. The use of the two innovations reported earlier should also be tested for cost-effectiveness on this type of road.



PROBABLE AREA OF PROBLEM	PREFERRED STRATEGY FROM TECHNICAL VIEWPOINT: *FUNDS ARE NO PROBLEM*	RECOMMENDATION WHEN *CAPITAL IS A PROBLEM*	
		RELATIVELY HIGH USAGE (TRAFFIC > 1000 AADT)	RELATIVELY LOW USAGE (TRAFFIC < 1000 AADT)
SURFACE, SUBBASE AND/OR SUBGRADE	REHABILITATE	(4)	(4)
SUBBASE AND/OR SUBGRADE	REHABILITATE	(4)	(4)
SURFACE	SEAL COAT	(1)	(1)
SURFACE	SEAL COAT	(1)	(2)
SURFACE	SEAL COAT	(3)	(3)
SURFACE	SEAL COAT	(3)	(3)
SURFACE	SEAL COAT	(1)	(1)
NORMAL WEAR	ROUTINE MAINTENANCE	(4)	(4)
SURFACE, SUBBASE AND/OR SUBGRADE	REHABILITATE OR RECONSTRUCT	(4)	(4)
SUBBASE AND/OR SUBGRADE	REHABILITATE	(4)	(4)
SURFACE	RESURFACE OR SEAL COAT	(1)	(2)
SURFACE	RESURFACE OR SEAL COAT	(1)	(2)
SURFACE	RESURFACE	(3)	(3)
SURFACE	SEAL COAT	(2)	(3)
SURFACE	SEAL COAT	(2)	(3)
NORMAL WEAR	ROUTINE MAINTENANCE	(4)	(4)

FIGURE 6 Recommended decision tree for seal coating decisions.

Seal Coating on High-Truck-Usage Roads

No structural strength is attributed to seal costs, so high volumes of heavy loads would be expected, from an engineering perspective, to cause greater damage. Seal coating on roadways carrying high volumes of trucks is not expected to last long enough to justify the investment. As such, it should be discouraged in practice.

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