ment at both the network and the project level. A methodology for evaluating these effects, based on pavement performance data and aggregated routine pavement maintenance cost information, has been described.

An application of the concept has been illustrated with a case study in which 75 highway routes in Indiana were analyzed. The proposed methodology was employed to compute for each highway route a routine pavement maintenance effectiveness index that is a measure of the effect of routine maintenance work on pavement performance. The magnitude of the index provides a means of assessing the effectiveness of a given maintenance policy or program. Statistical analyses were performed to examine the regional variation in effects of routine maintenance in Indiana. Research is under way to derive further information about the effects of routine maintenance by taking into consideration the influence of individual environmental and climatic factors and the effectiveness of specific routine maintenance activities.

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Estimation of Service Life and Cost of Routine Maintenance Activities

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Results of research on service life and cost of various routine maintenance activities in Indiana are presented. This research is a part of a larger project to develop an optimization program for the routine maintenance management system. The information on service life and cost is necessary to identify cost-effective solutions and to monitor whether or not changes in work practices or materials significantly influence the effectiveness of the activity. The routine maintenance activities considered were in the general areas of pavement, shoulder, and drainage. The unit cost information per production unit was obtained from an analysis of crew-day card reports. The service life data were developed through personal interviews with subdistrict foremen. The estimates of service life were related to pavement condition as well as to accomplishment per day. The resulting information provides a reasonable set of input data for the optimization of maintenance decisions.

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Interest in pavement maintenance management has grown steadily during the last 10 years or so. This interest has been largely motivated by a desire to obtain a greater degree of control and standardization of approach in order to ultimately achieve a better return per dollar invested in the construction and maintenance of pavements. However, most of the research that has been undertaken to date has been in the area of major maintenance. Consequently, there is limited published information on techniques and data concerning routine maintenance activities and management. The awareness of routine maintenance as a major consumer of limited highway funds is the motivating factor for the research being conducted at Purdue University to develop a routine maintenance management program for the Indiana Department of Highways (IDOH). Research on service life and costs of some of the routine maintenance activities in Indiana are described. These values were deemed to be essential inputs for such a program.

BACKGROUND

There is currently a maintenance management system (*1*) operating successfully at the network level in Indiana. The major features of the current system that are relevant to this research are (*a*) the field operators manual (*2*) and (*b*) crew-day cards. The field operators manual provides a set of performance standards for each designated maintenance activity. Each activity is identified by a number. The performance standard gives a description of the activity in question and a recommended maintenance procedure as well as a standard crew size, equipment complement, and a range of expected average daily production.

The crew-day cards provide a means of authorizing work to be done and recording work completed. One crew-day card is given to each crew leader every morning with details of the nature and location of the work to be done as well as assignment of employees and equipment. At the end of the day, the crew leader fills in the number of accomplishment units achieved that day, the man-hours worked, and the equipment and materials used. Thus it is possible to subsequently determine average man-hours, material usage, and other information per production unit.

This management system has been in operation in Indiana since 1975 and a large amount of data has been accumulated. The system has produced a relatively high degree of uniformity in maintenance procedures.

NEED FOR DATA

A variety of treatment alternatives exists for different types and levels of pavement and shoulder distress. All of these treatments will be effective to one degree or another, but there is a need to evaluate which methods produce the best solution to a given problem. To determine such an optimal solution, regardless of the nature of the deficiency, it is essential that two parameters be known, the service life and the cost of each of the alternatives.

The following uses have been put forward as justification for research on the estimation of expected service life and costs (*3, 4*):

1. To estimate and allocate available funds,
2. To identify the most cost-effective solutions,
3. To monitor whether changes in work practices or materials significantly increase service life and to evaluate whether such changes are cost-effective,
4. To identify locations where the expected life of a given treatment is consistently not attained,
5. To justify a change in emphasis at the network level; for example, advocating sealing (preventive maintenance) over patching (corrective maintenance),
6. To anticipate when necessary expenditures will recur, and
7. To coordinate with the pavement management system (PMS) and other management systems in working out the most cost-effective "holding" action until rehabilitation or reconstruction can take place.

DEFINITION OF PARAMETERS ESTIMATED

After the need for the data has been established, the next step is to determine how best to obtain the necessary information. A review of routine maintenance activities conducted by IDOH indicated that not all activities were of equal importance. Consequently, in the initial work a number of activities were selected from the general areas of pavement, shoulder, and highway drainage. The criteria applied in selecting the activities were (*a*) annual expenditure per activity and (*b*) annual volume of work performed per activity.

Service Life Estimates

The expected service life of any treatment may vary with the degree of deficiency of any particular distress type as well as from distress type to distress type. There are also unique influences peculiar to each general category of pavements, shoulders, and drainage.

A distinction between actual and effective service life must be made because it is crucial to understanding the uses to which the accumulated data can be put. The actual service life of a given treatment is regarded as the time elapsed between application of the treatment and when its condition falls below a prescribed, measurable value. In the present research, instead of using the actual service life of a treatment, an estimate of the effective service life was made to represent the time elapsed between the time the treatment is applied and that when, in the opinion of field personnel, it needs to be replaced.

In the establishment of a maintenance management program, what is of ultimate concern is the amount of money spent on any given activity and the way that available monies can be spent to produce the maximum good. Allocation of funds is basically carried out by field personnel. In the IDOH organization, geographic areas of responsibility for routine maintenance are broken down into districts, subdistricts, and units. A unit averages approximately 140 mi. Unit foremen are responsible for deciding in the first instance when and where work needs to be carried out. Hence, it is relevant and useful to obtain an estimate of how long a treatment lasts based on the opinion of the unit foreman.

This approach to service life estimation is not new or unique. Ontario has already carried out such a survey as part of its routine maintenance program (RMP) and has incorporated the results, both service life estimates and costs, into its overall RMP system (*5*).

There is no doubt that research needs to be done on actual service lives, however, so that, as such specific information becomes available in the future, the appropriate service life functions can be inserted in the proposed routine maintenance management program.

Cost Information

A large amount of research has been undertaken in recent years at Purdue on the overall and specific costs of routine maintenance activities in Indiana (*6, 7*). As a consequence of this prior research, it was possible to obtain a unit cost per production unit for each activity. Table 1 gives a summary of the unit cost data for each of the activities considered in the study. It was previously mentioned that crew-day cards were required to be filled in each day and that daily accomplishment was one of the values listed. Thus maintenance personnel are familiar with the concept of production units and with the variation in production caused by changing roadway or climatic conditions. It is also believed that using production units as an indirect measure of cost yields greater potential for transferability of results for comparison.

STRUCTURE OF QUESTIONNAIRE

A questionnaire was used to acquire service life estimates. The questionnaire is laid out in a tabular-matrix type of format. There are three categories of condition for each activity, which generally conform to the overall descriptors of poor, fair, and good, although there is some variation in definition depending on the particular activity in question.

The condition input is further subdivided into cells that consist of three components that roughly correspond to minimum, average, and maximum. All refer to service life estimates currently given by the unit foremen with available manpower, equipment, materials, and so on. A decision was made to look for minimum and maximum values as well as an average value because it was thought that, in terms of the overall range of performance, the average value alone could be misleading.

Minimum service life values are not intended to be the single worst case in the experience of the unit foreman but rather an indication of what is considered to be a realistic, poor service life value. Similarly, the maximum value is considered to reflect a generally high service life value as opposed to the longest service life history known to the unit foreman.

In a survey such as this, a decision must be made about the detail and accuracy of results that can be reasonably expected. A necessary trade-off must be made between the amount of data acquired and the consequent error induced in the respondents' estimates through boredom, desire to complete the survey rapidly, and so on. It is believed that the questionnaire used struck a reasonable compromise in this regard.

SURVEY METHODOLOGY

Implementation of the survey questionnaire involved consideration of where and how many interviews should be conducted. Indiana is divided into six administrative districts, each of which is comprised of a number of subdistricts. To interview personnel in all 37 of the subdistricts would have been extremely costly, time consuming, and difficult to arrange.

A decision was made to choose subdistricts to take part in

TABLE 1 PRODUCTION UNITS AND COSTS

ACTIVITY	PRODUCTION UNIT	TOTAL COST PER PROD. UNIT
Shallow Patching	Tons of Aggregate	$114.17
Premix Levelling	Tons of Premix	$41.46
Full Width Shoulder Seal	Foot Miles	$177.50
Seal Coating	Lane Miles	$1352.60
Long. Joint And Crack Sealing	Lineal Miles	$108.50
Crack Sealing	Lane Miles	$290.00
Spot Repair Of Unpaved Shoulders	Tons of Aggregate	$13.64
Blading Shoulders	Shoulder Miles	$13.73
Clipping Shoulders	Shoulder Miles	$205.50
Reconditioning Unpaved Shoulders	Shoulder Miles	$885.60
Clean and Reshape Ditches	Linear Feet of Ditch	$0.61
Motor Patrol Ditching	Ditch Miles	$377.80

the survey by a process of stratified random sampling. Two subdistricts were selected at random from each district. When the individual strata contain relatively homogeneous elements, the variability for a given stratified random sample will be less than in a simple random sample of the same size (i.e., the stratified sample is more efficient) (*8*).

Homogeneity for each stratum is considered reasonable in that each subdistrict within a district is subject to much the same climatic and topographic conditions and usually has the same source of maintenance materials and equipment. In addition, meetings of all subdistrict supervisors and general foremen occur on a regular basis, and consequently repair strategies and methods would be expected to be fairly consistent.

Discernible patterns in the service life estimates for a number of the activities were anticipated because of the large difference in climate and topography between northern and southern Indiana. The use of stratified sampling made it possible to examine and identify such patterns as well as to estimate the overall population characteristics. From the point of view of feasibility, the choice of two subdistricts from each district meant that it was generally possible to interview in two subdistricts each day, thus reducing time and travel costs. The entire survey was carried out in a 2-week period at the end of June 1985.

In general, at each subdistrict office a meeting was held with the general foreman and two unit foremen. A total of 33 maintenance personnel were interviewed. A personal interview approach was used instead of a mailed questionnaire to both reduce ambiguous responses and increase the response rate. It should be noted that the field personnel were extremely cooperative and knowledgeable in every instance. Care was taken to avoid asking leading questions and generally little prompting was required to get numerical estimates and justification for them.

ANALYSIS OF RESULTS

The results of the service life estimation survey are summarized in Tables 2–4 for pavement-related activities and in Tables 5 and 6 for shoulder- and drainage-related activities. A discussion of individual activities follows.

Shallow Patching

There are four subdivisions within this activity corresponding to the different possible materials used in patching. They are hot mix, cold mix, winter or fiber mix, and fiber mix heated in a Portapatcher. Each of these materials was treated as a separate subject of interest, and service life and accomplishments were recorded for all four types.

The effective service life of a patch was taken to be the time elapsed until more work was necessitated at the location where the patch was placed. This approach was taken because it was pointed out by maintenance personnel that although the material in the patch itself may remain in place for a considerable length of time, cracking and breakup at the edges of the patch

TABLE 2 SERVICE LIFE AND DAILY ACCOMPLISHMENTS FOR POOR ROADWAY CONDITION

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Shallow Patching Hot Mix	S.L.=2.8 APD =7.7	S.L.=8.5 APD =7.2	S.L.=12.5 APD =6.7
Shallow Patching Cold Mix	S.L.=0.2 APD =8.9	S.L.=0.3 APD =7.1	S.L.=0.7 APD =5.5
Shallow Patching Winter Mix	S.L.=1.0 APD =8.0	S.L.=3.7 APD =6.7	S.L.=3.8 APD =5.4
Shallow Patching Portapatcher	S.L.=1.3 APD =6.5	S.L.=5.3 APD =5.4	S.L.=7.3 APD =4.3
Premix Levelling (Wedging)	S.L.=17.1 APD =151	S.L.=24.9 APD =120	S.L.=30.9 APD =88
Seal Coat Chip Seal	S.L.=24.6 APD =5.0	S.L.=26.4 APD =6.3	S.L.=32.4 APD =7.8
Seal Coat Sand Seal	S.L.=0 APD =0	S.L.=0 APD =0	S.L.=0 APD =0
Sealing Long. Cracks & Joints	S.L.=17.7 APD =5.9	S.L.=22.5 APD =6.3	S.L.=26.2 APD =6.7
Sealing Cracks	S.L.=8.2 APD =1.2	S.L.=13.1 APD =1.5	S.L.=17.4 APD =1.8

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 1)

TABLE 3 SERVICE LIFE AND DAILY ACCOMPLISHMENTS FOR FAIR ROADWAY CONDITION

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Shallow Patching Hot Mix	S.L.=9.9 APD =4.4	S.L.=17.2 APD =4.2	S.L.=23.7 APD =4.2
Shallow Patching Cold Mix	S.L.=0.2 APD =4.7	S.L.=0.6 APD =3.9	S.L.=1.0 APD =3.3
Shallow Patching Winter Mix	S.L.=3.1 APD =4.6	S.L.=5.0 APD =4.0	S.L.=5.9 APD =3.3
Shallow Patching Portapatcher	S.L.=6.6 APD =4.8	S.L.=8.9 APD =3.8	S.L.=11.6 APD =2.8
Premix Levelling (Wedging)	S.L.=29.1 APD =105	S.L.=34.3 APD =89	S.L.=41.1 APD =69
Seal Coat Chip Seal	S.L.=31.8 APD =5.5	S.L.=37.4 APD =6.8	S.L.=45.6 APD =8.5
Seal Coat Sand Seal	S.L.=14.4 APD =6.2	S.L.=15.6 APD =8.2	S.L.=20.4 APD =10.8
Sealing Long. Cracks & Joints	S.L.=25.6 APD =8.0	S.L.=29.5 APD =8.4	S.L.=33.3 APD =9.1
Sealing Cracks	S.L.=13.6 APD =2.8	S.L.=19.9 APD =3.0	S.L.=24.5 APD =3.1

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 1)

TABLE 4 SERVICE LIFE AND DAILY ACCOMPLISHMENTS FOR GOOD ROADWAY CONDITION

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Shallow Patching Hot Mix	S.L.=36.0 APD =3.0	S.L.=53.4 APD =2.8	S.L.=54.2 APD =2.5
Shallow Patching Cold Mix	S.L.=0.3 APD =3.2	S.L.=0.7 APD =2.6	S.L.=1.2 APD =2.2
Shallow Patching Winter Mix	S.L.=3.3 APD =3.3	S.L.=5.8 APD =2.7	S.L.=6.8 APD =2.4
Shallow Patching Portapatcher	S.L.=14.7 APD =3.1	S.L.=23.1 APD =2.7	S.L.=24.1 APD =2.3
Premix Levelling (Wedging)	S.L.=36.0 APD =65.7	S.L.=47.1 APD =55	S.L.=49.7 APD =48
Seal Coat Chip Seal	S.L.=37.8 APD =6.2	S.L.=48.0 APD =7.5	S.L.=55.2 APD =9.1
Seal Coat Sand Seal	S.L.=19.2 APD =6.2	S.L.=21.6 APD =8.2	S.L.=28.8 APD =10.8
Sealing Long. Cracks & Joints	S.L.=31.6 APD =9.8	S.L.=34.9 APD =10.2	S.L.=38.2 APD =10.9
Sealing Cracks	S.L.=20.7 APD =4.1	S.L.=26.5 APD =4.5	S.L.=31.6 APD =4.9

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 1)

TABLE 5 SERVICE LIFE AND DAILY ACCOMPLISHMENTS FOR POOR SHOULDER AND DITCH CONDITION

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Full Width Shoulder Seal	S.L.=0 APD =0	S.L.=0 APD =0	S.L.=0 APD =0
Spot Repair Of Unpaved Shoulders	S.L.=3.0 APD =51.4	S.L.=4.7 APD =46.4	S.L.=6.2 APD =41.8
Blading Shoulders	S.L.=2.7 APD =10.2	S.L.=4.4 APD =10.6	S.L.=4.8 APD =11.3
Clipping Shoulders	S.L.=33.3 APD =1.5	S.L.=37.1 APD =1.9	S.L.=42.5 APD =2.3
Recondition Shoulders	S.L.=36.0 APD =3.3	S.L.=38.0 APD =3.4	S.L.=38.0 APD =3.4
Clean and Reshape Ditches	S.L.=28.6 APD =546	S.L.=30.8 APD =696	S.L.=34.4 APD =846
Motor Patrol Ditching	S.L.=28.9 APD =1.0	S.L.=29.8 APD =1.3	S.L.=30.5 APD =1.7

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 1)

may require early repair with additional patching. Patching accomplishments per day (APD) vary in an expected way, decreasing as roadway condition improves and decreasing as service life increases. This pattern is consistent for all four types of shallow patching.

Patching APD decreases with improving roadway condition simply because there is less severe distress at any one location and distressed locations are farther apart on a road in good condition than on a road in poor condition. There are two reasons why the service life and APD vary inversely for a given road condition. First, a location that yields a high APD generally exhibits a large amount of distress. Examples of sources of such distress are poor drainage and heavy traffic volumes. Undoubtedly the source will cause failure around the newly patched surface. Thus there is no cause-and-effect relationship between service life and APD per se in this case; both simply

TABLE 6 SERVICE LIFE AND DAILY ACCOMPLISHMENTS FOR FAIR SHOULDER AND DITCH CONDITION

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Full Width Shoulder Seal	S.L.=24.0 APD =65.0	S.L.=30.6 APD =73.5	S.L.=37.2 APD =83.5
Spot Repair Of Unpaved Shoulders	S.L.=6.3 APD =32.7	S.L.=8.3 APD =30.5	S.L.=10.9 APD =27.7
Blading Shoulders	S.L.=5.7 APD =12.4	S.L.=7.2 APD =13.2	S.L.=7.8 APD =14.4
Clipping Shoulders	S.L.=39.3 APD =2.8	S.L.=43.1 APD =3.2	S.L.=47.5 APD =3.7
Recondition Shoulders	S.L.=46.0 APD =4.5	S.L.=46.0 APD =4.5	S.L.=46.0 APD =4.5
Clean and Reshape Ditches	S.L.=42.7 APD =1082	S.L.=45.3 APD =1255	S.L.=48.0 APD =1436
Motor Patrol Ditching	S.L.=36.0 APD =1.7	S.L.=38.3 APD =2.0	S.L.=42.8 APD =2.5

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 1)

reflect the effect of the source of distress. Second, if the patch mix is placed more carefully and thoroughly, daily accomplishment will go down, but such care and thoroughness will be reflected in an increased effective service life. These two factors combined explain the difference in APD between minimum, average, and maximum for any given roadway condition.

Hot-Mix Patch

Hot-mix patching consistently has the highest estimate of effective service life. There are a number of reasons for this. First, the material is usually of superior quality and therefore is easier to place and compact than are the other three types of patching material. Also, hot mix is generally available only between April and October because plant production is limited to these months. Consequently, the climatic and road-base conditions are usually favorable for placement of the patch, which naturally leads to greater longevity.

It was generally considered that a hot-mix patch placed on a good road should last for the life of the road. Road life, represented by the resurfacing cycle, was taken to be 60 months for the purposes of calculation.

Cold-Mix Patch

Cold-mix patching material was considered by all personnel surveyed to be the poorest performer of the four types of patch material. The results given in Table 2 indicates that most service life estimates were given in days rather than months. The primary reason for this low service life is that the conditions under which the cold mix is placed make it difficult for the patch to hold. Cold mix is generally used in winter when no hot mix is available and consequently is placed in poor weather conditions that may cause the road base to be wet.

The combination of water and traffic loads can lead to early patch failure and, if snow ploughs are being used, the patches can be removed overnight. In addition, cold patch material as used is not adequate; it is prone to shoving.

Winter-Mix Patch

Winter-mix patching material is essentially a cold mix with fibers added to produce greater stability and resistance to shoving and is used under the same conditions as cold mix. Almost all personnel interviewed believed that the winter patch material was significantly better than cold mix in its ability to stay in position, and this opinion is reflected in the service life estimates obtained.

Winter-Mix Patch Using Portapatcher

A Portapatcher provides the facility to heat patching material. Heating patching material improves its workability for placement and compaction. Patches made with material heated in a Portapatcher were estimated to have a longer service life than patches made with cold mix. Personnel in two of the four northern subdistricts of IDOH expressed the opinion that the performance of winter mix heated in a Portapatcher was as good as that of patches made with hot mix.

In locations where flexibility and elasticity are important (e.g., on bridge decks) the heated fiber-mix patch appeared to perform better than a hot-mix patch. One drawback to using the Portapatcher is that a larger crew size is required.

Premix Leveling

Premix leveling or wedging involves placement of bituminous mixtures to correct depressions and rutting. Personnel in several subdistricts indicated that this activity is now primarily carried out by contract rather than by IDOH personnel. However, most subdistricts had sufficient experience to estimate service life and daily accomplishments.

The estimates follow an expected pattern for reasons similar to those mentioned in the discussion on patching. The primary reason given for early failure of wedging was that the roadway surface was not being tacked properly before application of the bituminous mixture.

In the case of premix leveling, a distinction was frequently made between service life when the material was placed using a grader and when it was placed using a paving machine. The prevailing opinion was that the paver produces a more uniform, better riding, and longer lasting surface.

Full-Width Shoulder Seal

Shoulder sealing involves seal coating of an existing paved shoulder. When the condition of the paved shoulder is poor, the general consensus of opinion was that a shoulder seal was not an appropriate treatment because no additional structural support is provided. The appropriate treatment of a paved shoulder in poor condition was deemed to be rebuilding.

Survey results indicate that service life and APD vary directly in shoulder sealing. The explanation for this relation is that the unit of accomplishment is foot miles. Thus a shoulder at the lower end of the fair range will require more work (and hence fewer miles covered) and yet will break up faster than a shoulder at the upper end of the range. Consequently, as in previous relations, the source of the deficiency establishes the relationship between accomplishment and service life. The major factor that influences the APD obtained is the width of the shoulder to be sealed because the unit of accomplishment is foot miles. Obviously a much higher APD will be obtainable on a 10-ft shoulder than on a 3-ft one.

Seal Coating

There are two subdivisions under the general heading of seal coating. These are chip seal treatments and sand seal treatments. As the names imply, they differ primarily in the aggregate coating used in the seal coating operation

Chip Seal

Chip sealing consists of coating full-width roadway sections with hot bituminous material and covering with No. 11 or No. 12 stone. One factor that can influence the service life obtained is the type of stone used in the surfacing operation; limestone chips were believed to be preferable to pea gravel.

The service life and APD pattern of seal coating is similar to that seen in the discussion of full-width shoulder seal. The major factor governing the APD was the haulage distance for bituminous material and aggregate rather than the roadway surface itself.

Sand Seal

The cover aggregate in sand seal is, as implied, sand rather than stone. Personnel in only five subdistricts believed they had sufficient experience to estimate sand seal values, although a number of the other subdistricts have begun to use this technique in the last two to three years. In general, it was thought that the sand seal was not effective on roadways in poor condition. On such surfaces, the sand seal does not prevent further deterioration or correct cracking for any appreciable length of time. The consensus of opinion was that on roads in fair or good condition, a sand seal is effective in sealing cracks and will contribute substantially to the longevity of road life. Personnel in one subdistrict reported that the sand seal was effective when placed over a "fatted" surface (i.e., a pavement surface with flushed asphalt) whereas the chip seal was better suited to dried-out pavements. The same trends in service life and APD observed in the shoulder seal activity are again evident here; there is a direct relationship between daily accomplishment and service life.

Sealing Longitudinal Cracks and Joints

Sealing longitudinal cracks and joints is accomplished by cleaning the cracks and joints and then filling them with liquid bituminous sealant. The usual method of crack and joint cleaning is to use a stream of compressed air to blow out the accumulated debris. An alternative method of cleaning the cracks and joints is to use a crack router attached to a tractor, but this operation is not considered here.

An examination of Tables 2–4 shows that there is not a large difference between maximum and minimum service life estimates of crack and joint sealing for any given roadway condition. However, the APD estimates for sealing do vary substantially as the condition of the roadway changes. This is to be expected because the accomplishment unit is linear miles and less sealing is required on a road in good condition than on a road in poor condition.

Sealing Cracks

The purpose of this activity is to clean and seal cracks in both bituminous and concrete roadways. Unlike the values for sealing longitudinal cracks and joints, the values obtained for sealing cracks show a marked difference between maximum and minimum service life for each roadway condition.

A definite relation exists between APD and roadway condition. This is to be expected because a workman will cover fewer lane miles as the amount of cracking increases.

Spot Repair of Unpaved Shoulders

Spot repair involves the repair of small areas of unpaved shoulders by adding aggregate and reshaping. Little significant difference exists overall in service life estimates given by personnel of the various subdistricts except for the minimum values of service life in the southern region of the state. A reason for this lower value may be the hilly topography of southern Indiana.

A strong influence on the service life of unpaved shoulder spot repair was believed to be rainfall in combination with high gradients. These factors, reinforced by traffic encroachment onto the shoulder at curves, provided the lowest estimate of service life. Service life and APD vary inversely for this activity because the accomplishment unit is tons of aggregate and the worst locations require more aggregate.

Blading Shoulders

Blading shoulders involves redistributing material and reshaping unpaved shoulders. Because the daily accomplishment unit is in shoulder miles, there is a direct relationship between service life and APD: the poorest locations yield the lowest service life and the lowest APD. The preferred equipment for this activity was a dump truck with scraper or underblade attached.

Clipping Shoulders

In shoulder clipping excess growth is removed from unpaved shoulders to restore adequate shoulder drainage. For a given shoulder condition, personnel in the southern subdistricts gave estimates of service life that were significantly under the overall average, and personnel in the northern subdistricts gave estimates of service life that were significantly above the overall average. The milder climate in southern Indiana, which encourages vegetable growth, may explain the difference.

A number of subdistricts distinguished between the APD using a front-end loader and what was variously described as a dirt loader, belt loader, or travel loader. The latter type of loader significantly increased the APD. Factors that influence the APD include the amount of sand to be cut and loaded and the haulage distance to a disposal site.

Reconditioning Unpaved Shoulders

Unpaved shoulder reconditioning involves adding aggregate and reshaping continuous sections of unpaved shoulder as opposed to spot repair, which is carried out at isolated locations. Personnel in none of the four southern subdistricts sampled had sufficient experience to estimate service life or APD for this activity. However, a comparison of service life and APD indicates that values for the central region were substantially lower than for the nothern region. A possible explanation of this difference is that the northern subdistricts tend to seal or oil the rebuilt shoulder in the same year that it is rebuilt, which should lead to a longer service life.

An examination of the results shows that in general there was little variation in the service life or the APD for a given shoulder condition. The main variable that influences accomplishment was generally thought to be the aggregate haulage distance.

Cleaning and Reshaping Ditches

Cleaning and reshaping ditches involves the excavation of dirt and debris from roadside ditches using a gradall that restores adequate drainage. Geography plays a major role in the estimates of both service life and APD. Personnel in the central and northern subdistricts did not vary excessively in their estimates; estimates of both service life and APD were much lower in the southern subdistricts, and within the southern region the subdistricts farthest south were significantly lower in their estimation.

These results indicate that topography and soil conditions play an important role in the rapidity and extent of ditch blockage; in areas with steep hills, heavy rainfall, and poor soil conditions, the effective service life is low. For the same reason, the APD, measured in lineal feet of ditch, is also low in such areas. Another factor that influences the APD obtained is the distance that material must be hauled from the ditch for disposal. An interesting point that was often repeated in discussion with maintenance personnel was that daily production can be very misleading. In a ditch that is badly clogged with debris, it may be necessary to make two or three passes with the excavator to restore an adequate cross section. However, this extra work does not show up in the daily record. This is the basic reason why an examination of Tables 4 and 5 shows such a large variation in APD with ditch condition.

Motor Patrol Ditching

Motor patrol ditching, as the name implies, involves cleaning of ditches using a motor patrol rather than a gradall. There was much discussion of the advantages and disadvantages of the two methods. In one southern subdistrict, motor patrol ditching is not carried out at all because of the difficulty of operating such equipment on hilly terrain with heavily blocked ditches. Other limitations on using motor patrols for cleaning ditches include difficulty of operation in wet weather and in areas of clayey soils with steep ditches. Conditions favorable to motor patrol ditching include operation in dry weather and in areas with sandy soil and on flat, wide ditches. The consensus of opinion was that the gradall produces a better, more rounded, and longer lasting ditch cross section than does the motor patrol. A comparison of the values of APD shows that motor patrol ditching, measured in ditch miles, has a higher production rate than does gradall ditching, which is measured in feet. The principal explanation of this is that motor patrol ditching is limited to wide areas where few obstructions are present. The main factor that governs the APD attained is the distance the debris must be hauled from the ditch to a designated dump site.

CONCLUSIONS

The overall goal of this research is to further evolve a functioning system for routine maintenance management in Indiana. Results reported in this paper provide a first, meaningful estimate of service life for a major portion of the routine maintenance activities engaged in by the IDOH. Records and prior research were used to determine both APD and costs for the various activities, and these values were tabulated. Now that service life, APD, and cost are known, basic information is available for establishing the framework of a maintenance management system that will address optimal allocation of maintenance resources. Specifically, the data reported here will give initial estimates for parameters that are necessary to make a management system possible. Further research is being conducted that will, over a period of time, provide more definitive functional relations for maintenance activity service life. In the meantime, the information generated in the survey can furnish a reasonable set of input data for use in the optimization of maintenance decisions.

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