SUMMARY

This paper describes the requirements of long-term pavement monitoring studies to collect data for use in the development of multiple regression relations among pavement types, traffic loadings, environmental factors, and other important parameters. The study approach for this paper is aimed specifically at defining data requirements that would support development of multiple regression relations, but it is hoped that a reasonable amount of the data might be common to data-collection activities for other purposes, such as identifying needs for maintenance or rehabilitation, project design, and budgeting funds for these activities.

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Simplified Pavement Management at the Network Level

R. DARYL PEDIGO AND W. RONALD HUDSON

A simplified pavement management system at the network level is presented, and an example is provided to demonstrate how this framework can be applied to produce a priority ranking on a network basis. This framework has been specifically designed to be independent of the organization of any specific highway agency. The framework is organized around the flow of information on either management level, and three major subsystems are identified at each level. Essential features of pavement management systems are identified, and specific characteristics are described for the example models and outputs. Existing pavement management practices are reviewed to demonstrate several different levels at which pavement management activities are occurring in U.S. agencies. The findings of the study suggest that implementation of simple systems can probably best begin at the network level of pavement management. These simple steps can be coordinated with later development work to recognize analysis of alternatives and optimization at the network level. A research plan and problem statements are included to address continued development and implementation at both the network and project levels.

Pavement management is a concept that involves the coordination, scheduling, and accomplishment of all of the activities performed by a highway agency in the process of providing adequate pavements for the public. The systems approach to pavement management is a rational, highly structured process that attempts to achieve the best value possible for the public funds expended to provide pavements. This is accomplished by comparing investment alternatives; coordinating design, construction, maintenance, and evaluation activities; and making efficient use of existing methods and knowledge (1). Of course, management decisions are made each day in the course of normal operations of highway agencies throughout the nation. The purpose of a pavement management system (PMS) is to improve the efficiency of this decision-making process, expand its scope, provide feedback regarding the consequences of decisions and the results of activities, and ensure the consistency of decisions made at different levels within the same organization (2).

Many agencies and individuals have conducted research into the various component models and procedures involved in pavement management. A significant portion of this work has been summarized in two recent books (1,3), which suggest that there are several major underlying considerations in pavement management:

1. Management decisions occur at several levels, ranging from investment decisions covering the network to detailed design decisions at the individual project level.
2. Periodic, in-service evaluation of existing pavements is basic to the programming of rehabilitation and maintenance, the updating of earlier design estimates, and the improvement of models.
3. A PMS must be capable of being adapted to the varying needs and resources of different agencies in order to be implemented. It must also be capable of serving the various management levels noted in item 1 above.

These considerations led to the development of a general framework for PMSs during the first phase of research under this project (2). A major finding of this study is that most PMS development and experience to date have occurred at the project level and within the areas of design or maintenance. This

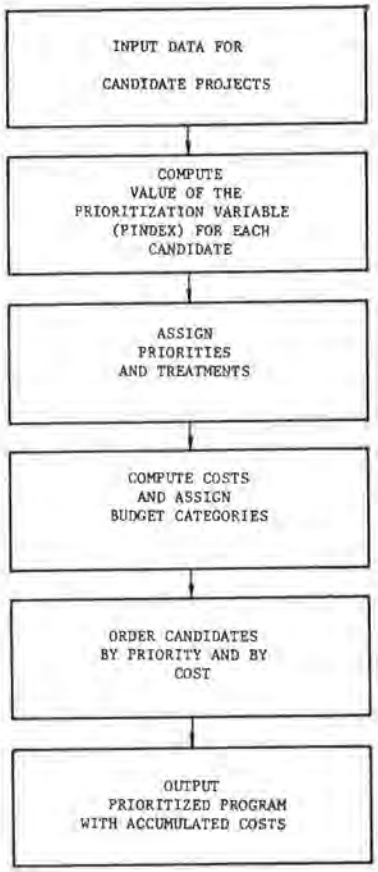


Figure 1. Basic steps in rehabilitation programming.

concentration of effort has produced many significant results, and it has also created a void in network-level development. Consequently, the greatest current need is for a comparable focusing of effort at the network level. This need derives largely from the concurrent need to preserve investments in existing pavements and to obtain the maximum value for limited available dollars. A major portion of these funds is required for rehabilitation, which makes this a prime area for the concentration of initial development. This is in consonance with the findings of the Tumwater Workshop on Pavement Management (4).

A PMS is a tool for use in decisionmaking; as such, it is highly specific and particularly structured to the attitudes and procedures of the implementing agency. Consequently, many of the details of a PMS must be fit or molded by the implementing agency. Nevertheless, significant portions of the development and implementation work involved in setting up and operating a PMS are potentially applicable to a wide variety of uses.

SIMPLIFIED NETWORK-LEVEL PMS

A simplified PMS for network-level rehabilitation programming (PMS-N), based on the framework and characteristics discussed above, is presented here. The system to be described represents a "bare-minimum" PMS-N. However, this paper provides recommendations and examples for upgrading this simplified system, as envisioned in Figure 1.

The desired result for a PMS-N is a specified program of work to be performed annually, including rehabilitation and maintenance. Ideally, this would include a list of projects to be rehabilitated during each construction season over a period of 5-20 years. The simplified version considers programs one year at a time and provides a prioritized listing of projects to be rehabilitated during the last year of the program.

The basic steps in a simplified programming scheme are shown in Figure 1. These represent the minimum procedures required for programming in a PMS-N and comprise a subset of the 15 steps in the priority programming process identified in a recent synthesis report (5).

Input Data for Candidate Projects

The information required for the technical, nontechnical, and economic analyses to be carried out in subsequent steps must be provided for those projects that are candidates for rehabilitation during the programming period. The bare-minimum data required for the simplified PMS-N are as follows:

1. Project identifiers--(a) Project limits (description) and (b) milepost or control section numbers;
2. Project characteristics--(a) Length, number of lanes, and lane width, (b) pavement type and last rehabilitation, (c) functional classification, and (d) shoulder type and width;
3. Engineering data--(a) All variables required for the calculation of the prioritization variable (PINDEX) (as a minimum, the serviceability index), (b) safety variables, if not included in item a (as a minimum, skid number of accident rates), and (c) traffic variables [as a minimum, average daily traffic (ADT)];
4. Nontechnical data--Identifier to flag "committed" projects; and
5. Economic data--(a) "Average" costs may be used as a minimum, so that no data will be required for individual projects, and (b) eligible budget category or categories.

Candidate projects must be selected before prioritization can be carried out. For a small highway network, it may be convenient to consider all pavement sections as candidates, whereas for a larger network a screening process may be necessary to reduce the data-collection and analysis efforts. One possible screening method involves the routine monitoring of a simple variable, such as serviceability, for all roadway sections. Then, based on the value of this variable, the "worst" 25-50 percent of the existing pavements may be chosen for further analysis. Alternatively, each district could be charged with selecting candidates, or the agency may use its existing procedure for project selection. In any event, it is desirable that the candidate selection process be compatible with the prioritization analysis. For example, if roughness is to play a large part in determining rehabilitation priorities, then the selection process should be designed to ensure that all very rough pavements are considered for inclusion as candidates.

Once candidates have been selected, the project identifiers and project characteristics listed above must be recorded in the PMS data base. This data base may be a separate computer file or a set of data records exclusively for the PMS function, or it may be simply a master list that indicates where all of the necessary individual data elements may be found. In either case, the information must be readily accessible to the PMS staff, and such access is efficiently provided in a computerized data management system.

The same type of information must be provided for all projects. For example, either mileposts or control section numbers can be used to identify a project, but it is unacceptable to use milepost identifiers for some projects and control section numbers for others. In addition, all data must be keyed to the same identifier. Thus, if construction information is currently reported by control section and engineering data are reported by milepost, it will be necessary to convert from milepost to control section (or vice versa) in setting up the PMS data base. This can be a troublesome undertaking, but some states (e.g., Washington) have already accomplished such a conversion.

The engineering data collected on each project must be updated on a regular schedule. Generally, data will be collected on each section each year; however, this requirement may be relaxed to allow data collection every other year or every third year on pavements that are known to be in good condition. Such decisions are made on the basis of budget, manpower, and equipment constraints, and it is preferable to carry out a limited monitoring program accurately and completely rather than to hastily and partially perform a more comprehensive survey. However, it should also be remembered that these data are to be used for overall judgments only and that those candidates that appear in the final work program will generally require further scrutiny before any rehabilitation activity is performed. It is therefore desirable to limit the scope of the data collected for the determination of the prioritization variable (PINDEX) and to gather more complete data only on those projects that make the cut. Thus, the obvious or most simple choice (PINDEX = the existing sufficiency rating) may not prove to be the best choice in every agency.

For example, suppose that a sufficiency rating is currently performed in programming projects for rehabilitation. A typical sufficiency rating procedure involves three factors (condition, safety, and service), and each factor requires the evaluation of approximately five variables (6). In addition, many states now include three other type factors (environmental, social, and economic), each of which also involves several variables. This means that 15-30 or more variables must be measured or assessed in order to arrive at a sufficiency rating. When faced with the prospect of gathering such information systemwide, an agency might well decide that it can only afford to carry out such a rating on one-half or one-third of the highway system annually. For prioritization purposes, the agency may feel that it is more important to have reliable, current information of a less extensive nature on the entire network each year. If this is the case, PINDEX should be constructed from only a few of the most crucial sufficiency variables. In fact, a single variable may be chosen as the PINDEX if the agency feels that this variable provides enough information to allow a meaningful prioritization. We feel that serviceability is the best candidate for a single-variable PINDEX but that it would also be preferable to incorporate other variables into PINDEX if resources are available to do so.

Safety variables may, of course, be directly incorporated in the calculation of PINDEX. However, during the course of this research, we discussed this possibility with representatives of several highway agencies. The vast majority of those consulted indicated a desire or preference for developing a separate program of safety-related projects or in any case to avoid assigning specific weights to safety variables in relation to pavement condition variables. Only a few persons indicated that it would be desirable to incorporate safety variables in the determination of PINDEX. Hence, we have developed a procedure that treats safety variables independently without impact on the value of PINDEX. The prioritization procedure may be used with or without the safety module so that safety projects may be totally excluded from consideration in the simplified PMS-N if the agency so desires.

Analysis of Data and Computation of PINDEX

The prioritization procedure for the simplified PMS-N is summarized in Figure 2, which is an expanded version of Figure 1. The first element of this procedure is the development of a complete list of candidate projects along with the data on each project that are required for prioritization and economic analysis. Any candidates that have already been approved in other programs are deleted from further consideration. Those projects that have been held over from previous years, "promised" to local governments or other agencies, or otherwise previously committed for completion are assigned highest priority and are not technically evaluated.

Next, the remaining projects are evaluated. The value of PINDEX is calculated for each project from the input data according to the method selected by the agency. Any number of variables may be used by the agency in constructing the prioritization variable PINDEX, but it is recommended that no more than three variables be used in the initial implementation of this procedure. The definition of PINDEX may be extended fairly easily to incorporate additional variables, if so desired, after some experience is gained in the operation and results of this procedure.

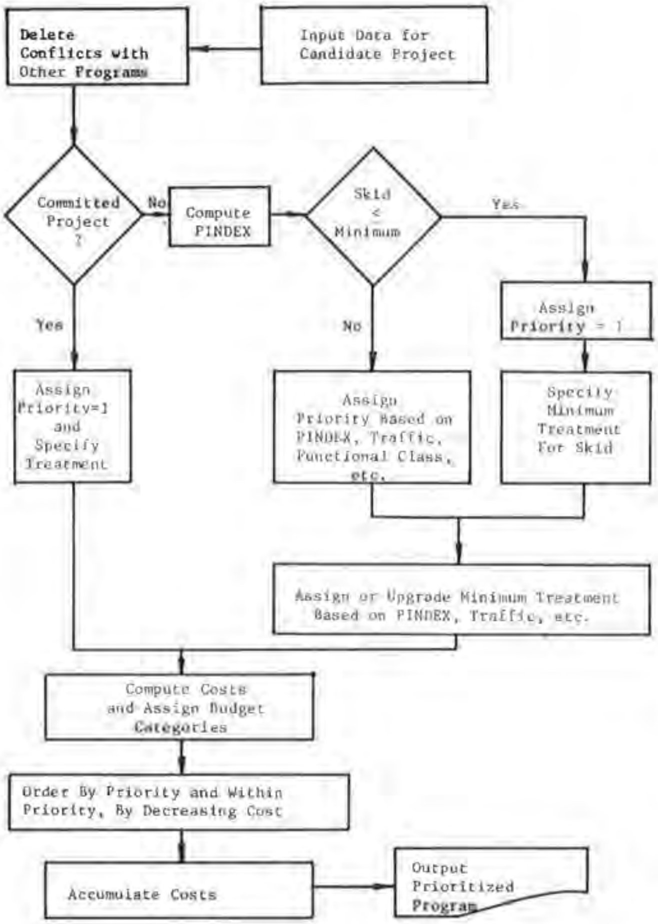
Once the value of PINDEX has been computed, the projects may be prioritized. However, as mentioned previously, an option has been provided at this point for the treatment of safety projects outside the framework of the PINDEX calculation. For this purpose, skid number (SN_{40}), as measured by almost every state by using a standard American Society of Testing and Materials skid trailer, has been selected as the safety variable. This choice was made for example purposes because this variable is almost universally recognized, is easily measured, and appears in the form of an easily understandable numerical index. Another safety-related variable, such as accident rate or wet-weather-safety index, could easily be substituted in this procedure should the agency so desire.

The value of skid number recorded for each project is compared with a fixed minimum value determined by the agency. If the minimum standard for safety is not met, the project is assigned highest priority and a minimum treatment to correct this deficiency is assigned. The agency must choose an appropriate minimum treatment, and it is recommended that several alternative minimum treatments be specified, depending as a minimum on the functional class of roadway involved and the level of traffic to be carried.

If the minimum standard for safety is met or exceeded, the project is assigned a priority based on the value of PINDEX. In the case of safety projects, all deficient projects received highest priority; however, for resurfacing or structural rehabilitation it will be desirable to assign highest priority to major roadways that have high traffic volumes. Hence, priority is to be determined on the basis of functional class of roadway and ADT as well as PINDEX.

At this point, a minimum treatment is assigned to each project on the basis of PINDEX, ADT, and functional class of roadway. This minimum treatment represents the least costly action that can be carried out to return a deficient section to acceptable condition or maintain an adequate section in acceptable condition. As before, in assigning such

Figure 2. Flowchart of prioritization procedure.



minimum treatments the agency should consider not only the condition of the pavement but also the functional class and level of traffic. However, the priority of the project should not have a direct impact on the nature of the treatment (it will, of course, ultimately determine whether or not the treatment is carried out). The exception to this rule is that the lowest-priority projects will virtually always receive a treatment such as "no rehabilitation--continue routine maintenance".

A list of example minimum treatment options and some example criteria for their application is provided later in this paper.

Output

Since a main purpose of the simplified PMS-N is to produce a prioritized program, the major output report must be a listing of this program of work. It should be remembered, however, that the information collected and the analysis performed may prove useful for other purposes as well. Hence, several types of optional output may be prepared. For example, a listing of the total estimated quantities of materials needed to carry out the program, or a listing of the average condition of the existing highway network by functional class, might be desirable. If the PMS-N is computerized, such output reports will be relatively easy to develop, produce, and modify. In fact, this flexibility in generating output is one of the major benefits derived from a computerized PMS.

The exact nature of these optional reports will be very agency dependent. The primary output report will, of course, also depend on the needs of the individual agency, but generally very similar types of information on the prioritized program will be needed by most agencies. It is, therefore, this primary output report that is treated here.

The minimum information content of the primary output report on the prioritized program of work is as follows:

1. Project identifiers--(a) Project limits (description) and (b) milepost or control selection numbers;
2. Technical information--(a) Priority assigned to the project, (b) summary of the deficiencies for which treatment is recommended (as a minimum, a numeric or alpha-numeric code indicating the general nature of the deficiency or deficiencies); and (c) recommended minimum treatment as a bare minimum (this may be a simple code, such as M = continue maintenance or R = rehabilitate); and
3. Economic information--(a) Cost of the proposed treatment, (b) allocation of this cost to eligible budget categories (as a minimum, a simple list of eligible budget categories), and (c) cumulative costs of this project and all higher-priority projects.

In general, it is recommended that the projects be listed in order of decreasing priority and that projects of equal priority be listed in order of decreasing cost. This may, of course, be modified by the agency so that projects may be listed by district, budget category, functional class, or in any other useful arrangement. If a priority value is listed for each project, no information will be lost by reorganizing the output listing.

APPLICATIONS, INTERPRETATION, AND APPRAISAL

The findings of this project are now brought into a more practical focus. As an illustration of the applicability of the techniques discussed in the preceding section, a detailed sample problem is worked out. This sample problem is for illustrative purposes only and is neither totally representative of typical conditions nor directly applicable to any existing highway agency.

Following the sample problem, a phased implementation plan for a network-level PMS is presented. This plan is intended to assist highway agencies in implementing the techniques described in this paper. Some specific guidelines for application of these principles are also discussed, and the current practices of several states are reviewed.

Sample Problem

The specific values quoted in this example problem were chosen on the basis of experience and discussions with representatives of various highway agencies. The problem itself is worked out in sufficient detail to provide step-by-step guidance for agencies that wish to develop their own systems along these lines. It must be emphasized that the specific choices of variables and values to be used in the simplified PMS-N are extremely agency dependent. Consequently, the specific choices given here are not recommendations; they are examples only. Each agency must assess its own needs and make its own choices regarding the relevant variables to be used, standards to be adopted, terminal values, etc.

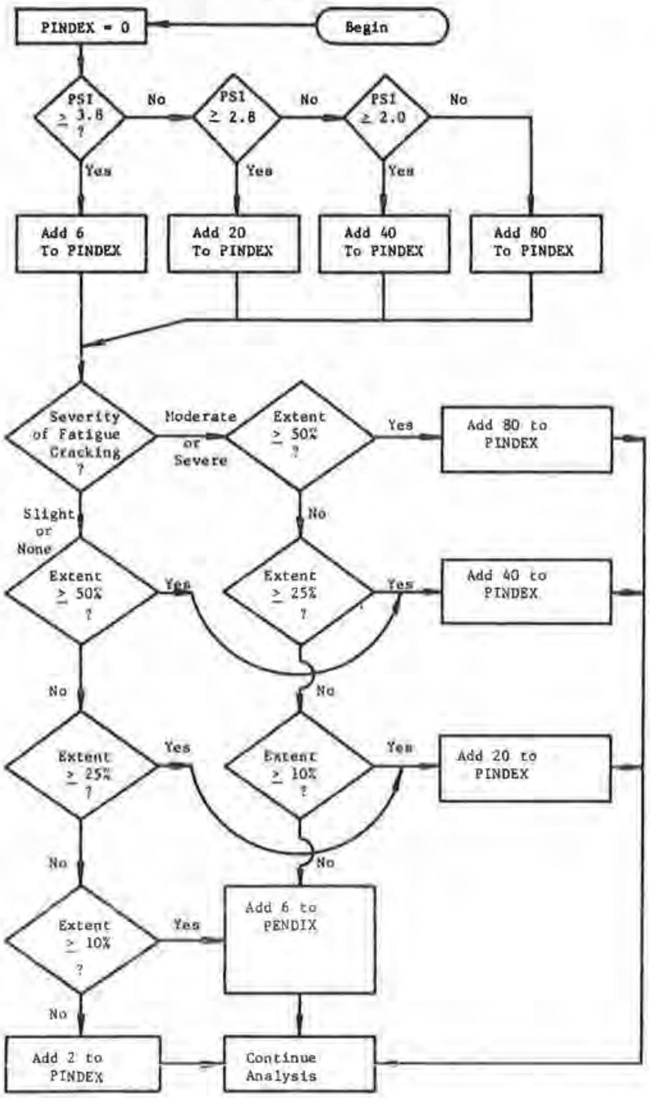
The input data for the eight candidate projects chosen for the sample problem are given in Table 1. These data are based on actual values taken from field studies, modified to produce the desired range

Table 1. Project input for sample problem.

Project Identification	Milepost Begin	Milepost End	Lanes No.	Lanes Width (ft)	Pavement Type	Functional Class	Avg PSI	Fatigue Criteria Severity	Fatigue Criteria Extent (%)	ADT
51-FI-0356700-E	100.4	105.0	2	12	AC-overlay[a]	Principal arterial	2.4	None		6 000
54-MA-0356712-S	16.3	18.7	1	12	AC	Local	2.6	Slight	30	500
05-ST-0311130-S	6.5	8.0	2	12	AC	Minor collector	2.1	Moderate	60	1 400
26-CO-0356700-N	7.5	9.3	1	12	AC	Minor arterial	1.9	Slight	10	4 200
52-KI-0330000-W	43.8	46.5	2	12	AC-overlay[a]	Principal arterial	3.1	Slight	5	12 500
58-OA-0330001-N	27.3	30.8	1	12	AC	Major collector	2.9	Severe	5	3 900
75-AP-0330006-N	11.2	15.3	1	12	AC	Minor arterial	2.7	Slight	15	4 000
05-ED-0311130-S	9.4	12.7	1	12	AC	Local	2.0	Severe	60	600

Note: PSI = present serviceability index and AC = asphalt concrete.
[a]Portland cement concrete.

Figure 3. Calculation of PINDEX for sample problem.



of solutions. Since the significant variables, terminal values, and treatment options will vary with pavement type, only pavements with asphaltic concrete (AC) surfacing were chosen. Portland cement concrete pavements can of course be treated in a similar fashion.

Arbitrary project identification codes were assigned to each project for illustrative purposes. In practice, each agency will have its own coding system for identifying projects. Beginning and ending milepost values are coded according to an imagined state route milepost system. These projects range in length from approximately 1 to 5 miles. Both twoand four-lane roadways are included; however, projects are defined in this sample problem according to the direction of traffic flow so that the number of lanes quoted represents the number of lanes in the direction of traffic flow.

Since it will generally be necessary to consider programs that involve pavements of different functional classes, the sample problem includes arterial, collector, and local roadways. ADT levels range from 500 to 12 500. The average values of serviceability and distress recorded in Table 1 represent roadways in less-than-desirable condition--i.e., roadways that are candidates for rehabilitation.

The economic input required for the sample problem involves only average unit costs for potential rehabilitation actions, since this approach does not require project-specific cost calculations. The required values are specified below (SAMI = stress-absorbing membrane interlayer):

Rehabilitation Action	Avg Cost ($/yd²/ unit of thickness)
AC overlay	2.25
AC leveling course	2.32
Place new AC	2.25
Replace cracked areas with 6-in AC	19.20
Cold plane	3.25
Heater plane	1.47
Heater scarify and compact	0.60
Remove existing AC	0.50
Full-depth AC	2.25
Fabric in traffic lanes	1.21
SAMI in traffic lanes	2.00
Chip seal	0.55
No rehabilitation, continue maintenance	0.00

Again, although these costs are believed to be reasonable for each listed activity, these values are included for illustrative purposes only and should not be used by any agency without independent verification.

For simplicity, no safety variables are considered in this example, and no projects are preselected as "committed". In addition, no attempt has been made to assign projects to different budget categories.

For each of these projects, it is necessary to calculate a value of PINDEX. The logic for accomplishing this calculation is illustrated in Figure 3. Two variables have been chosen for use in calculating PINDEX: PSI and fatigue cracking. These variables were chosen for illustrative purposes and are not being "recommended". We do feel, however, that PSI offers an inexpensive, reasonable, overall assessment of the adequacy of a pavement to serve traffic and, in conjunction with structural and/or condition survey variables, can be used to prioritize and derive generalized rehabilitation strategies for programming purposes. Fatigue cracking was chosen as a significant condition indicator that could be used along with PSI in this fashion. Each agency must select a set of variables that is appropriate to its purpose and experience. For example, many agencies feel that deflection information would be very useful for such purposes, and this choice certainly could be used within the simplified PMS-N. In choosing an appropriate set of variables, it should be kept in mind that the methodology recommended here is to be applied for programming purposes only. It will be desirable to supplement this information with additional data in order to finalize the rehabilitation design for any particular project (and update the program accordingly) before work is actually carried out.

The calculation of PINDEX in this sample problem involves the categorization of the condition of the pavement by values of PSI and the severity and extent of fatigue cracking. The categories chosen for this sample problem are given in the two tables below:

Serviceability Category	PSI
Very good	3.8-5.0
Good	2.8-3.7
Fair	2.0-2.8
Poor	2.0

Fatigue-Cracking Category	Severity	Extent (%)
Excellent	Slight	10
Very good	Slight-moderate	10-25
	Severe	10
Good	Slight	25-49
	Moderate-severe	10-25
Fair	Slight	50
	Moderate-severe	25-49
Poor	Moderate-severe	>50

The specific values chosen to delineate these categories were developed on the basis of the experience of project staff. However, the number of categories and their specific delimiters are examples rather than recommendations.

The values added to PINDEX in Figure 3, which depend on the specific PSI or fatigue category into which the project falls, were also chosen based on their experience. We believe that the values are reasonable, but, again, they are illustrative values only. These values were chosen so that pavements that fall into the "poor" category of either PSI or fatigue will achieve a relatively high priority for rehabilitation. Pavements that fall into the "fair" category for either PSI or fatigue will receive considerably less emphasis.

The next step in the simplified PMS-N involves the development of treatment options and the assignment of priorities. For this sample problem, all treatment options (with the exception of the option "no rehabilitation, continue maintenance") will provide a new surface for the roadway, thus automatically improving any serviceability problem. Hence, the specific range of treatment options to be considered for a project will be selected on the basis of the severity and extent of fatigue cracking. The logic for this selection process is shown in Figure 4. Notice that PSI is considered only if the project falls into the "excellent" category for fatigue cracking and that, in this case, only those projects that fail to meet a minimum PSI standard will be rehabilitated. For example purposes, minimum PSI standards of 2.5 for Interstate and arterial roadways and 2.0 for all other roadways were selected. These values were chosen for illustrative purposes only and are not to be considered recommendations.

The specific rehabilitation actions that make up each option list are discussed subsequently in the sample problem.

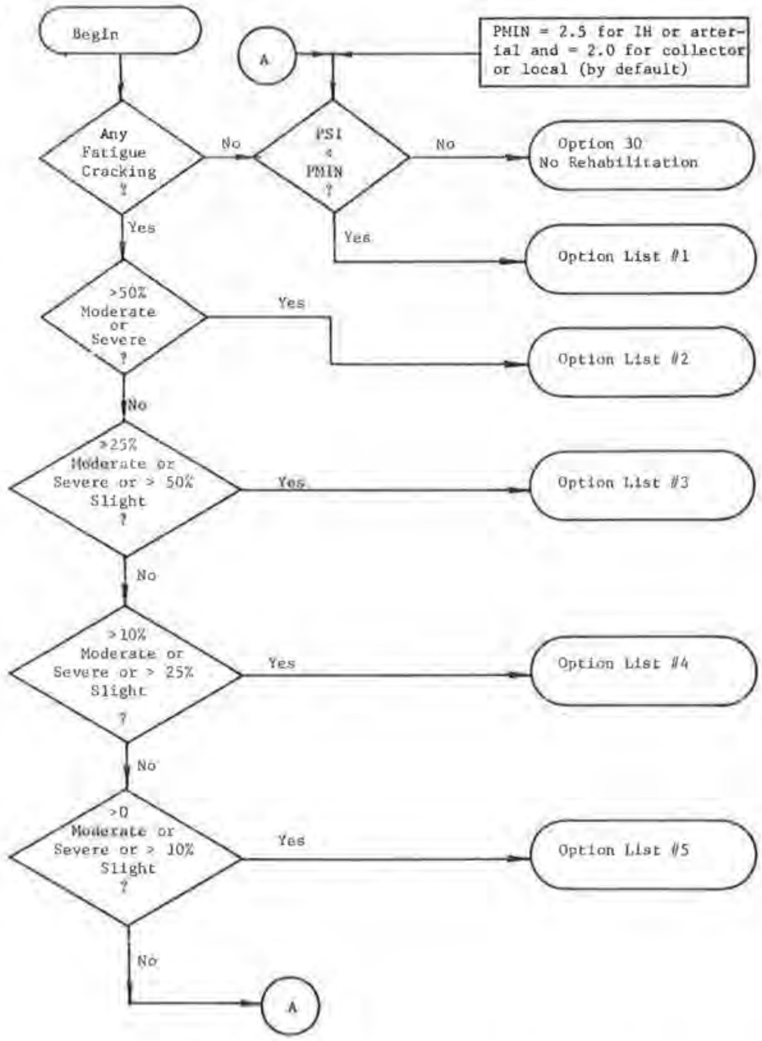
The prioritization of projects of mixed functional classes and varying traffic levels could hardly be carried out on the basis of the PINDEX obtained from Figure 3, since the values in Figure 3 make no distinction between local roadways and Interstate highways or between roadways with low traffic and similar roadways with high traffic. In order to take such variations into account, the value of PINDEX may be adjusted to reflect the relative priority of projects with roughly equal serviceability and fatigue cracking in various functional classes and with various traffic levels. Table 2 gives a list of factors that may be multiplied by PINDEX in order to assign greater priority to the higher functional class and also to assign greater priority to roadways with high traffic levels within a given functional class. As with all numerical values in this sample problem, the values of this multiplicative factor were chosen to provide reasonable answers for illustrative purposes only. Similarly, the specific numbers of vehicles given in Table 2 are not intended to be representative but were chosen only for use with the sample problem.

The logic of the prioritization process is shown in Figure 5. The value of PINDEX, as calculated through the procedure of Figure 3, is used as input to the procedure of Figure 5. This value of PINDEX, on a 0-100 scale, is multiplied by the appropriate factor for functional class and ADT to obtain an adjusted PINDEX. It is this adjusted value of PINDEX that is used in assigning relative priorities to the projects. For this example problem, projects may be classified as priority 1, priority 2, or priority 3. It is important to note that projects will be ranked by the value of PINDEX within each priority class, so that certain priority-1 projects will be of higher priority than other priority-1 projects. The priority value is used merely as a rough indicator to separate projects into those that are very urgent and those that are in less immediate need.

The prioritization and treatment-selection processes described above were applied to each of the eight candidate projects given in Table 1. The results are presented in Table 3 and the two tables below. Table 3 is a sample output report that contains a prioritized listing of the candidate projects based on the value of PINDEX calculated from the procedure illustrated in Figure 5. For each project, a set of treatment options has been selected according to the logic presented in Figure 4. These options are described in the tables below. The first table gives sample problem rehabilitation options, and the second table gives option lists for the sample problem:

Option	Description
1	Cold plane, 1.0 in; new AC, 1.5 in
2	Heater plane, 1.5 in; new AC, 1.5 in
3	AC level, 1.0 in; AC overlay, 1.0 in
4	Remove existing AC; new AC
5	AC overlay, 1.5 in
6	Heater plane, 0.75 in; new AC, 1.0 in

Figure 4. Selection of rehabilitation option.



Option	Description
7	Cold plane, 1.0 in; new AC, 1.0 in
8	Cold plane, 1.0 in; SAMI; new AC, 1.0 in
9	AC level, 1.0 in; fabric; new AC, 1.0 in
10	Remove existing AC + 1.0 in base; new AC
11	Fabric; new AC, 1.5 in
12	Heater plane, 0.75 in; new AC, 1.5 in
13	Cold plane, 1.0 in; SAMI; new AC, 1.5 in
20	Apply chip seal
22	AC overlay, 1.0 in
30	No current rehabilitation, continue maintenance

Option List No.	ADT	Option No.
1	>X	1,2,3,4
	<X	5,6,7
2	>X	8,9,10
	<X	11,13
3	>X	8,9,10
	<X	11,13
4	>X	1,2,3,4
	<X	5,6,7,12
5	>X	22
	<X	20

Table 2. Example prioritization factors based on functional class and ADT.

Functional Class	ADT Level	ADT No. of Vehicles	Factor
Interstate	High		1.00
	Medium		0.95
	Low		0.88
Principal arterial	High	>15 000	0.93
	Medium	5-15 000	0.87
	Low	<5000	0.80
Minor arterial	High	>12 000	0.83
	Medium	4-12 000	0.75
	Low	<4000	0.68
Major collector	High	>8000	0.73
	Medium	2-8000	0.65
	Low	<2000	0.60
Minor collector	High	>5000	0.60
	Medium	1-5000	0.53
	Low	<1000	0.45
Local	High	>3000	0.55
	Medium	500-3000	0.45
	Low	<500	0.35

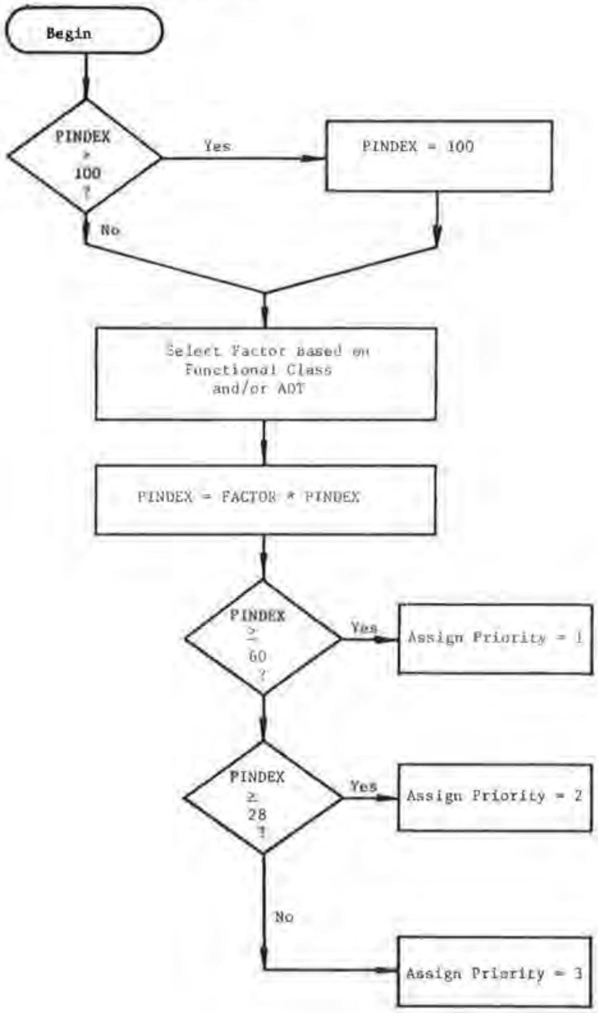
Cost figures are also presented for each project in Table 3. For each project, the minimum-cost treatment option was selected from the list of potential treatments, and the cost associated with that minimum-cost option was calculated by using the values identified in the text table on page 34. This minimum cost is listed for each project in Table 3 along with a cumulative cost that assumes that the minimum-cost treatment will be applied to each project in order of decreasing priority.

Notice that there is only a single priority-1 project among those in Table 3. This occurred in the sample calculation because the arterial roadways were found to be in relatively good condition and the prioritization factors listed in Table 2 automatically reduce the emphasis given to collectors and locals. The selection of priority 1, 2, or 3, illustrated in Figure 5, is purely arbitrary and may be omitted from the PMS-N without changing the order of ranking based on PINDEX.

It is also interesting to note that project 52-KI-0330000-W is listed in Table 3 as requiring no rehabilitation, even though it has a higher priority than project 58-OA-0330001-N, which does require rehabilitation. The former project retains a higher priority because it is a principle arterial with a fairly high traffic volume, whereas the latter is a major collector with a moderate traffic volume. The inclusion of such "no rehabilitation needed" projects will have no effect on cost factors associated with the program of work but will provide a flag for the decisionmaker when the proposed program of work is reviewed. The presence of a large number of such projects in the prioritized output list could indicate that the prioritization factors in Table 2 and/or the treatment-selection process in Figure 4 should be modified. In fact, the specific variables and values chosen by an agency in setting up a prioritization procedure should be subject to constant review and revision in order to upgrade the value of the recommended programs of work at each iteration of the procedure.

Finally, a comparative ranking of the candidate projects in the sample problem on the basis of serviceability index alone is provided in Table 4. Notice that the order of the projects is by no means the same as in Table 3; however, the changes are generally shifts in order by only one or two places rather than between the top of the list and the bottom. This is to be expected, since the value of PINDEX is based on serviceability and on fatigue cracking and those pavements that have very low serviceability will also generally exhibit appreciable fatigue cracking. It should be noted, however, that those pavements in higher functional classes and with higher traffic levels (Table 1) have moved up the list in Table 3 relative to their placement in Table 4. This illustrates the value of the weighted prioritization process in Figure 5 and Table 2.

Figure 5. Prioritization process.



Implementation of PMS

The simplified PMS-N described earlier and illustrated in the sample problem may be adapted and implemented by pavement management teams from a variety of highway agencies. Implementation of a PMS is of necessity a unique and individual undertaking related to individual organizational characteristics, funding levels, and needs. The purpose of this project has been to present a generalized, simplified PMS that can serve as a guide for use and development in several state highway departments. In this section, some general background guidelines on implementation are presented, as well as a series of individual factors that can be used to benefit specific implementation plans.

The reader who is expecting a step-by-step cookbook on pavement management implementation will no doubt be disappointed in this paper. Experience shows that it is no more possible to develop a

Table 3. Sample problem results.

Ranking	Project Identification	Milepost Begin	Milepost End	Priority	PINDEX	Avg PSI	Fatigue Cracking Severity	Fatigue Cracking Extent (%)	Option List	Treatment Options	Minimum Cost ($000s)	Cumulative Minimum Cost ($000s)
1	26-CO-0356700-N	7.5	9.3	1	65	1.9	Slight	10	1	5[a], 6, 7	42.8	42.8
2	05-ST-0311130-S	6.5	8.0	2	53	2.1	Moderate	60	2	11[a], 13	84.2	127.0
3	05-ED-0311130-S	9.4	12.7	2	45	2.0	Severe	60	2	8, 9[a], 10	134.3	261.3
4	51-FI-0356700-E	100.4	105.0	2	37	2.4	–	–	1	5[a], 6, 7	218.9	480.2
5	75-AP-0330006-N	11.2	15.3	2	35	2.7	Slight	15	5	22[a]	64.9	545.1
6	54-MA-0356712-S	16.3	18.7	3	27	2.6	Slight	30	4	5[a], 6, 7, 12	57.1	602.2
7	52-KI-0330000-W	43.8	46.5	3	19	3.1	Slight	5	–	30[a]	0	602.2
8	58-OA-0330001-S	27.3	30.8	3	17	2.9	Severe	5	5	22[a]	55.4	657.6

[a]Minimum-cost treatment.

Table 4. Sample problem candidate projects ranked by serviceability.

Ranking	Project Identification	Milepost Begin	Milepost End	Avg PSI	PINDEX	Ranking in Table 3
1	26-CO-0356700-N	7.5	9.3	1.9	65	1
2	05-ED-0311130-S	9.4	12.7	2.0	45	3
3	05-ST-0311130-S	6.5	8.0	2.1	53	2
4	51-FI-0356700-E	100.4	105.0	2.4	37	4
5	54-MA-0356712-S	16.3	18.7	2.6	27	6
6	75-AP-0330006-N	11.2	15.3	2.7	35	5
7	58-OA-0330001-N	27.3	30.8	2.9	17	8
8	52-KI-0330000-W	43.8	46.5	3.1	19	7

single complete guideline for implementing pavement management than it is to write a simple, complete marriage manual that is directly applicable to all cases and all couples.

The following listing presents the major items in a summary implementation plan for major consideration:

1. Decision to start;
2. Preparation of goals, objectives, and preliminary budget;
3. Commitment from top management (usually network level first);
4. Preliminary work plan (form technical group);
5. Establishment of a steering committee (administration);
6. Development of a detailed work plan;
7. Evaluation of hardware and software needs;
8. Development of the preliminary system (network and level);
9. Testing and verification of the preliminary system;
10. Demonstration of the second-stage system;
11. Finding a home for the PMS group in the organization;
12. Acceptance of the PMS for implementation;
13. Routine operation of the system; and
14. Improvement, upgrading, and maintenance of the PMS.

Note that this summary includes 11 items to be accomplished prior to routine operation of the system; these range from a decision to start to acceptance of the PMS for implementation. It may appear that some of the items are self-evident; however, making a specific overt decision at each of these points is extremely important. Each of the points is discussed in more detail elsewhere (7).

SUMMARY AND SUGGESTED RESEARCH

The experience and research presented in this paper point to a continued need for PMS development and implementation. This may sound all too familiar to the reader, but in this case much remains to be done. As highway budget levels shrink in the face of inflationary cost increases and growing traffic levels, it will be increasingly important to apply systematic pavement management in a comprehensive, coordinated fashion.

Most PMS development and experience to date have occurred at the project level and within the areas of design or maintenance. Development has focused quite naturally and understandably on these areas, and this concentration of effort has produced significant results.

Currently, the major concerns in pavement management lie at the network level. Consequently, the greatest current need is for a focusing of research effort at the network level. This paper has addressed network-level PMS development, but substantial additional effort is required to "catch up" with project-level technology. This effort would include extensive development of network-level subsystems and prediction models as well as trial implementation of network-level systems and combined project- and network-level systems.

A PMS useful in decisionmaking is a highly specific tool that is particularly structured to the attitudes and procedures of the implementing agency. Consequently, many of the details of a PMS must be fitted or molded directly to the implementing agency. Nevertheless, significant portions of the development and implementation work involved in setting up and operating a PMS are potentially applicable to a wide variety of users. This type of work is most suitable for National Cooperative Highway Research Program funding.

Thus, two general types of effort are needed for comprehensive PMS development: (a) the detailed work that must be done by individual states and (b) the more general development that can be effectively carried out on a common national scale. A plan for future research of general applicability, including suggested research activities at both the project and network levels and estimated costs, is translated into a specific set of problem statements in the Appendix of the report by Pedigo, Roberts, and Hudson (8).

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