Development of a Preventive Maintenance Algorithm for Use in Pavement Management Systems

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A primary objective of Pavement Management Systems is to maintain pavements in good condition at the lowest possible cost. Preventive maintenance treatments play an important role in prolonging service life by slowing down pavement deterioration. This paper documents the development of a preventive maintenance algorithm and introduces a new concept in determining distress density limits for the recommendation of preventive maintenance treatments. A literature search was performed in order to evaluate preventive maintenance algorithms currently in use. Common to existing preventive maintenance algorithms is the use of the subjective judgment of pavement engineers to determine distress density ranges. The procedure described in this paper, which was developed at the United States Army Construction Engineering Research Laboratory, relates distress density directly to the Pavement Condition Index used in the PAVER Pavement Management System. The concepts presented in this paper can be used by any agency to fully develop a preventive maintenance algorithm. The procedure described can be applied to both asphalt concrete and portland cement concrete pavements, and is flexible enough to allow for local policies and economic factors. The initial algorithm may be expanded to include environmental or geographic factors and additional preventive maintenance treatments at a later date.

As the infrastructure of pavements in the United States continues to deteriorate, many agencies are using Pavement Management Systems (PMS) as an aid in maintaining pavements in good condition at the lowest possible cost. An effective PMS should include

1. Data storage and report generation;
2. Network management tools, including prediction of pavement condition, budget planning, and inspection scheduling; and
3. Project management tools, including pavement condition history, construction history, and economic analysis for determining the most cost-effective maintenance and repair (M&R) strategy.

The timing of M&R repairs can be an important factor in maintaining pavements economically. Typical pavement deterioration curves depict pavement life cycles as consisting of two phases *(1)*. During the first phase, a 40 percent deterioration of pavement condition gradually occurs over 75 percent of the life of the pavement. As the second phase begins, a sharp decrease in condition occurs. An equivalent 40 percent drop in condition takes place within only 12 percent of the life of the pavement. Pavement M&R costs at this point are 4 to 5 times as high as those at the end of the first phase. If pavement repairs are performed while the pavement is still in the first phase, rather than waiting until the sharp decline to a poor or failed condition, costs can be greatly reduced. A method of deterring the onslaught of the sharp decrease in condition is to perform appropriate preventive maintenance techniques to pavements relatively free of surface distresses. The function of these preventive maintenance techniques is to slow down pavement deterioration in order to prolong service life.

The objective of this paper is to document the development of a preventive maintenance algorithm for use in Pavement Management Systems. The PAVER Pavement Management System, developed by the U.S. Army Construction Engineering Research Laboratory (USA-CERL), will be used to demonstrate the applicability of the algorithm. However, the logic followed throughout the development is equally applicable to any PMS. This paper will also introduce a new concept in determining distress density limits for identifying appropriate preventive maintenance strategies. The concept presented is an improvement over existing subjective approaches.

DEVELOPMENT OF THE PAVEMENT CONDITION INDEX (PCI)

In order to predict future pavement conditions, a Pavement Management System must have an objective, repeatable measurement rating. The PAVER System is based on the Pavement Condition Index (PCI). The development of the PCI is well documented *(2)*. It is important to explain the concepts behind the PCI for an understanding of the components of the preventive maintenance algorithm presented later in this paper. The PCI will be used in the determination of which pavements should be recommended for preventive maintenance, and one of the steps used in calculating the PCI is fundamental to a major portion of the preventive maintenance algorithm.

There were three objectives to be met in the development of the PCI. It was meant to provide: *(a)* an index of present condition in terms of both structural integrity and surface

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operational condition, *(b)* an objective, rational basis for determining M&R needs and priorities, and *(c)* a warning system for the early identification or projection of major repair requirements or both *(3)*. The PCI is based on three pavement distress characteristics: distress type, severity, and quantity. These three characteristics are evaluated according to a standardized rating system, and the PCI, a numerical condition index between 0 and 100, is determined.

Because of the large number of possible distress type/severity/quantity combinations that are possible, the major problem was the development of one index that would take into account all three factors. The following equation was found to be a comprehensive and accurate model for expressing a condition index *(3)*.

$$PCI = C - \sum_{i=1}^{p} \sum_{j=1}^{m_i} a\,[\,T_i, S_j, D_{ij}]\,F\,(t, d)$$

where

PCI = pavement condition index;
C = a constant depending on desired maximum scale value;
a [ ] = deduct weighting value depending on distress type T_i, level of severity S_j, and density of distress D_{ij};
i = counter for distress types;
j = counter for severity levels;
p = total number of distress types of pavement type under consideration;
m_i = number of severity levels on the ith type of distress; and
$F(t, d)$ = an adjustment factor for multiple distresses that varies with total summed deduct value (t) and number of deducts (d).

Acceptable distress definitions and deduct values were developed over several years through extensive field testing and revisions by a group of experienced pavement engineers. During field testing, a subjective pavement condition rating (PCR) was determined for each section of pavement in addition to a calculated PCI. In order to calculate the PCI, deduct values were preliminarily assigned to all distress type/severity level combinations based on distress density [(amount of distress/area of sample unit) × 100]. The deduct values were meant to serve as a type of weighting factor that indicated the size of the effect that the particular distress type/severity level/distress density combination had on the pavement condition. The deduct curves for alligator cracking on roads and streets are shown in Figure 1.

Once all the deduct values had been determined for each distress type/severity level combination identified in the pavement survey, the total number of deducts was summed. The total deduct value was then corrected based on the number of deducts and subtracted from 100, which was chosen to be representative of a pavement in perfect condition. Many revisions were made until the calculated PCI could closely correlate with the average PCR value.

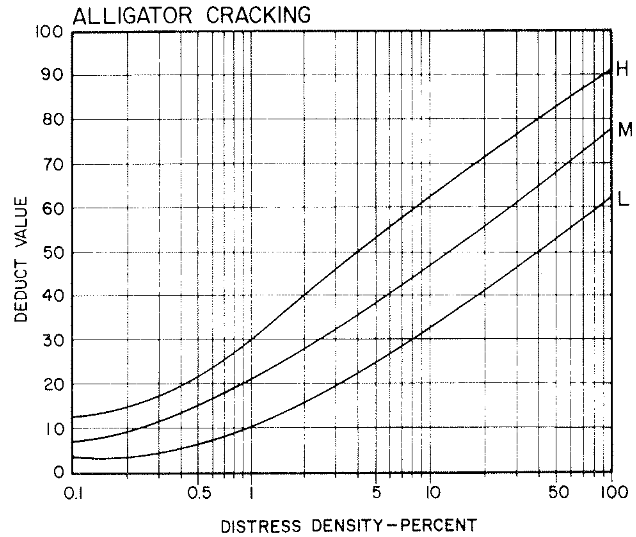

FIGURE 1 Deduct value curves for alligator cracking.

Based on the input from the field testing and evaluation procedure, accurate descriptions of distress types, severity levels, and the corresponding deduct values were derived so that a composite distress index (PCI) could be determined. The continued ability of the PCI to represent the subjective rating of pavement engineers was recently confirmed in a study done in the San Francisco Bay area *(4)*. In that study, inspections using both subjective ratings and the PCI rating procedures were performed on Bay area pavements to test the accuracy of the deduct and multiple-distress correction curves. Results of the regression analysis on the collected data indicated a high correlation between the mean subjective rating (PCR) and PCI ($R^2 = 0.86$). Through years of field use, the PCI has continually been found to be an objective, repeatable scale (within ± 5 points with 95 percent confidence) of the collective judgment of experienced pavement engineers.

PREVENTIVE MAINTENANCE CONCEPTS

In a study conducted for USA-CERL by the Texas Transportation Institute/Texas A&M University (TTI/A&M), a comprehensive literature search was done to investigate existing strategies for the selection of M&R alternatives at various agencies *(5)*. Incorporated into the M&R algorithms used by the agencies is the selection of preventive maintenance treatments for pavements with little or no structural damage. Pavements with significant structural deficiencies must be rehabilitated with more appropriate M&R techniques. A summary of the approaches used by the California Department of Transportation, Texas State Department of Highways and Public Transportation (SDHPT), the San Francisco Bay Area, and the PAVER Pavement Management System is presented here.

In 1979, the California DOT implemented a PMS that featured M&R strategies based on the experience of agency engineers *(6, 7)*. The selection of a final repair technique for asphalt concrete pavements involves four basic steps. First, a survey is performed that determines the extent and severity of eight possible distress types. Each distress identified in a pavement section is entered into a decision tree to identify all possible solutions for the lane, as shown in Figure 2, for alligator, block,

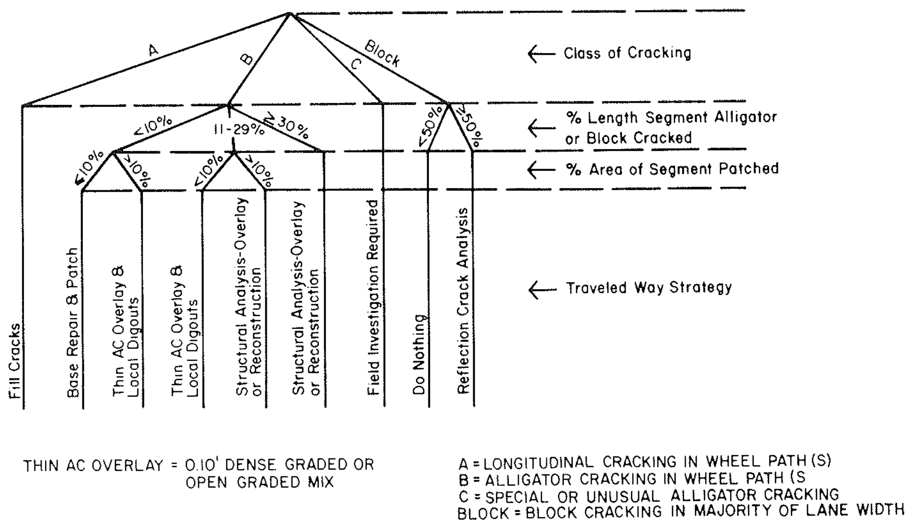

FIGURE 2 California DOT decision tree for flexible pavement alligator/block/longitudinal cracking.

or longitudinal cracking. Once alternatives have been identified, the second step is to compare each individual strategy and determine the one that will correct all the existing distresses in the lane. This strategy is referred to as the dominant strategy. The next step is to identify a compatible strategy that takes into consideration the dominant strategies for the shoulder and each pavement lane. Finally, all identified compatible strategies are listed in order of priority based on ride, distress rating, and average daily traffic (ADT).

The Texas SDHPT recently revised their PMS to include the selection of preventive maintenance requirements *(8, 9)*. Initially, their PMS was used as a network level tool that identified pavements in need of major M&R work and estimated budget requirements.

The decision on whether a pavement section is selected for rehabilitation is based on the pavement's condition rating. Texas uses a distress and serviceability rating consisting of seven surface distress types. A condition rating between 0 and 100 is determined with a score of 100 representing a pavement in perfect condition. Pavements identified as having a condition rating of less than 35 are flagged for rehabilitation consideration.

The Department found that a great deal of the work being proposed was for pavements with relatively high ratings (i.e., 55 to 75). Because these pavements were not identified as needing structural improvements, they were treated as candidates for preventive maintenance activities.

The preventive maintenance algorithm uses a decision trees procedure, such as that shown in Figure 3, which is based on the following criteria:

1. Pavement type (7 types of flexible pavements are defined),
2. Type and extent of pavement distress, and
3. Traffic level (4 levels are defined).

An appropriate maintenance strategy is identified for each pavement type/distress type/distress extent/traffic level combination. The maintenance strategies used in the Texas PMS are shown in Table 1.

Following the selection of possible alternatives, a dominant strategy is selected that ranks the selected strategies in order of their ability to repair multiple distresses. Once a procedure has been selected, the program then makes additional checks to identify the need for any necessary maintenance requirements.

The San Francisco Bay area PMS uses the PCI as an indicator of pavement condition *(4)*. In order to determine sections in need of M&R work, the most recent PCI is used with a PCI prediction technique to project the condition throughout a 5-year analysis period. These values are entered into selection criteria that specify the PCI ranges and deterioration rates for four M&R categories: major rehabilitation, overall rehabilitation, light rehabilitation, and a preventive maintenance program.

In this system, preventive maintenance is recommended for those sections with a PCI greater than 70 or a PCI that will not go below 70 in any of the first 3 years of the analysis program. Once identified as a preventive maintenance candidate, the present condition, projected condition, and any previously applied preventive maintenance treatments are all considered in the recommendation about which technique to apply. A series

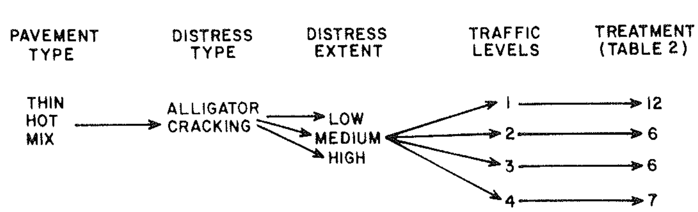

FIGURE 3 Example of one branch of Texas decision tree.

TABLE 1 MAINTENANCE STRATEGIES CONSIDERED IN THE TEXAS PAVEMENT EVALUATION SYSTEM

Maintenance Strategies	
Number	Name
0	Do Nothing
1	Seal Cracks
2	Partial Patch
3	Full Depth Patch
4	Fog Seal
5	Strip Seal
6	Seal Coat
7	Asphalt-Rubber Seal
8	Slurry Seal
9	Level-up
10	Thin Overlay
11	Rotomill
12	Spot Seal
13	Rotomill + Seal Coat
14	Rotomill + Thin Overlay

of treatments such as surface treatments, crack sealing, or skin patching is typically scheduled according to a predetermined time sequence.

A section will remain in the preventive maintenance program until either the PCI drops below 70 or a maximum allowable number of successive seal coats has been applied. Table 2 lists the preventive maintenance policy default values used in the PMS for crack seal intervals and maximum allowable number of successive seal coats. The user has the option of overriding the default values if, for example, a thin overlay is determined to be more appropriate than a seal coat on a high-volume road.

The existing PAVER PMS uses two tables, one each for flexible and rigid pavements, in the selection of appropriate maintenance strategies *(10)*. The guidelines for flexible pavements, as shown in Table 3, and those for PCC pavements, were intended to be applied to pavements with high PCI values. Using Table 3 as a starting point, the TTI/A&M study laid much of the groundwork in the development of a proposed preventive maintenance algorithm for the PAVER system. The selection of appropriate preventive maintenance treatments for candidate sections is based primarily on surface distress conditions and pavement rank. Pavement rank is used in the PAVER system as an indication of the functional classification of a pavement.

PREVENTIVE MAINTENANCE ALGORITHM DEVELOPMENT

As already mentioned, the objective of this paper is to outline the development of an algorithm for the recommendation of

TABLE 2 SAN FRANCISCO PREVENTIVE MAINTENANCE POLICY

		Number of Successive Seals Prior to Overlay or Removal	
Surface Type/ Branch Use	Crack Seal Interval	Chip Seals	Slurry Seals
AC ART	3 YRS	2	2
AC COL	4 YRS	2	3
AC RES/LOC	4 YRS	2	4
AC/AC ART	3 YRS	2	
AC/AC COL	4 YRS	2	
AC/AC RES/LOC	4 YRS	2	
AC/PCC ART	3 YRS	2	
AC/PCC COL	4 YRS	2	
AC/PCC RES/LOC	4 YRS	2	
ST COL	3 YRS		
ST RES/LOC	4 YRS		

Note: AC = asphalt surfaced, ART = arterial, AC/AC = asphalt surfaced overlaid with asphalt, COL = collector, AC/PCC = rigid pavement overlaid with asphalt, ST = surface treatment (armor coat) pavement, and RES/LOC = residential/local.

TABLE 3 PAVER PROCEDURE FOR IDENTIFYING M&R ALTERNATIVES FOR FLEXIBLE PAVEMENTS

Distress Type \ M&R Method	Do Nothing	Crack Seal	Partial Depth Patch	Full Depth Patch	Skin Patch	Pothole Filling	Apply Heat & Roll Sand	Apply Surface Seal Emulsion	Apply Rejuvenation	Apply Aggregate Seal Coat	Notes
1 Alligator Cracking			M,H	M,H				L	L		
2 Bleeding	L						L,M,H				
3 Block Cracking	L	L,M,H							L	L,M	
4 Bumps & Sags	L		M,H	M,H	M,H						
5 Corrugation	L		M,H	M,H							
6 Depression	L		M,H	M,H	M,H						
7 Edge Cracking	L	L,M	M,H	M,H							If predominant, apply shoulder seal, e.g., aggregate seal coat.
8 Joint Reflective Cracking	L	L,M,H	H								
9 Lane/ Shoulder Drop Off	L										If predominant level off shoulder and apply aggregate seal coat
10 Longitudinal Transverse Cracking	L	L,M,H	H					L	L	L,M	
11 Patching & Utility Cut	L	M	H*	H*							*Replace patch
12 Polished Aggregate	A									A	
13 Potholes			L	L,M,H		L,M,H					
14 Railroad Crossing	L				L,M,H						
15 Rutting	L		L,M,H	M,H	L,M,H						
16 Shoving	L		M,H								
17 Slippage Cracking	L	L	M,H								
18 Swell	L			M,H							
19 Weathering & Raveling	L		H					L,M	L	M,H	

Note: L = low severity; M = medium severity; H = high severity A = has only one severity level.

preventive maintenance strategies. The concepts described can be applied to both AC and PCC pavements, and can include any preventive maintenance treatments used by an agency. The initial algorithm is expandable so that environmental or geographical factors can be added at a later date.

Many factors are likely to influence the development of a preventive maintenance algorithm. Each agency must make decisions about appropriate strategies that conform to local policies and minimum pavement condition levels. Some of the factors that influenced the development of the algorithm used in this paper are presented here.

1. Agencies require a flexible algorithn. .at allows them to tailor the selection criteria according to local needs and policies.

2. It was found that most agencies will not typically apply seal coats and slurry seals to high-volume pavements. Often, crack seals and thin overlays are the only strategies recommended for this type of pavement. This assumption was adopted in the development of the algorithm.

3. Little information was available concern which preventive maintenance techniques work well under various environmental conditions.

4. Different climatic zones affect pavement deterioration rates in different ways. Factors such as amount of rainfall, type of subgrade, and number of freeze-thaw cycles influence the pavement deterioration rate if preventive maintenance is deferred. Average conditions were assumed in the development of the algorithm because insufficient information was available regarding the incorporation of climatic factors into the system. The proposed algorithm is flexible enough to allow for the addition of climatic factors as more data become available.

5. A trigger value should be set to indicate the lower boundary in the selection of candidate sections for preventive maintenance. A PCI default value of 70 was used as the trigger value in the development of this algorithm. Agencies will have the option of overriding the default value.

6. It was felt that small amounts of severe distress should not preclude a section from being selected for preventive maintenance. For that reason, patching was included as a repair procedure that could be recommended before the application of preventive maintenance activities.

7. All distress types identified in a section should be considered so that large amounts of severe distress, where restorative procedures may be more appropriate, are identified.

An effective preventive maintenance algorithm should consider certain fundamental steps. The flowchart shown in Figure 4 traces the logic used in the developed procedure. The concepts on which each step is based are outlined below.

Step 1: Define Parameters

The first step in the proposed algorithm is for the agency to define the parameters for the selection of candidate sections eligible for preventive maintenance and the strategies that should be included in the strategy selection tables. The agency would have the option of selecting preventive maintenance activities from the default strategy tables stored in the data base, or modifying these tables to fit local needs and policies. The default strategy tables may include preventive maintenance treatments such as crack sealing, patching, slurry seals, chip seals, and thin overlays. If strategy tables are developed for various pavement functional classifications, any restrictions on the use of certain activities on particular pavement ranks can be incorporated into the decision process.

Included in the development of strategy selection tables is the identification of upgrading strategies for any alternative excluded from consideration. The default upgrade strategy would permit slurry seals to be upgraded to chip seals, chip seals to be upgraded to thin overlays, and thin overlays to be upgraded to no preventive treatment (i.e., major rehabilitation) if the former treatment is excluded. Any modifications to the upgrading-strategy process should be made by the agency. This step ensures that only eligible treatments be considered throughout the remaining portion of the algorithm.

Another parameter that needs to be defined includes the minimum PCI above which a preventive maintenance strategy is recommended. Any sections with a PCI above the default value should be considered eligible for preventive maintenance. The recommended default value is a PCI of 70. Below this value, more corrective or structural types of M&R activities would normally be required.

Finally, unit costs for each of the possible preventive maintenance treatments should be entered. Generally, costs are entered in terms of dollars per square foot, with the exception of some activities (e.g., crack sealing) that would be more appropriate in units of dollars per linear foot.

Step 2: Check Eligibility

Once the parameters have been defined, the data base is searched to determine which sections fall within the established parameters. In addition to checking the defined parameters, the suitability of applying preventive maintenance treatments to each section should be examined by asking questions that may alert the agency to any unusual conditions. Typical questions could include the following:

1. Does the latest PCI of the section fall outside the specified (or default) PCI range?
2. Is the required AC overlay thickness needed for the section greater than 2.5 in.?
3. Does the pavement have a high deterioration rate?

If the answer to any of these questions is yes, the section should no longer be considered for preventive maintenance and project level investigations should be performed.

Step 3: Generate Density/Severity Classifications

After the candidate sections have been identified, density/severity classifications should be determined. Unlike other preventive maintenance algorithms, which base density ranges on the subjective judgment of a few engineers, this procedure, developed at USA-CERL, relates distress density ranges directly to PCI deduct values. Three ranges of PCI deduct points corresponding to an acceptable amount of distress should be

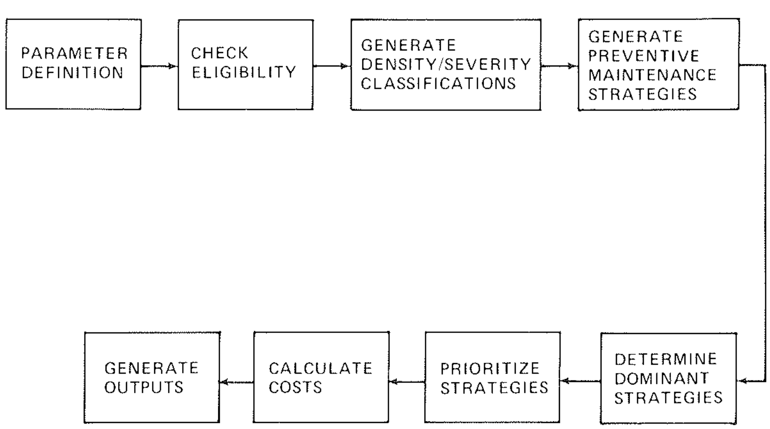

FIGURE 4 Preventive maintenance algorithm flowchart.

established for each of the three density levels: low, medium, and high. To accomplish this, the densities corresponding to each of the deduct ranges must be determined for all distress type/severity level combinations. The advantage to this approach is that the amount of deterioration that each distress type/severity level combination causes on the pavement is derived from an objective rating scale that was used to determine PCI deduct values.

Because deduct values serve as a type of weighting factor that indicates the size of the effect that the particular distress type/severity level has on pavement condition, they can be used as a quantifiable indication of the amount of damage allowed within each of the three density ranges for each defined distress type and severity level. Through extensive use of the PCI, the reliability of the deduct curves to represent the subjective rating of experienced pavement engineers has been accepted.

To demonstrate the use of this concept in a preventive maintenance algorithm, polynomial curve-fitting techniques developed at USA-CERL were used to derive equations for the PAVER PCI deduct curves. A total of 104 curves were fitted for each of the defined distress type/severity level combinations for asphalt concrete (AC) and PCC pavements. As an example, Figure 5 shows a fourth-order fit for low-severity alligator cracking. If fourth-order curves were not found to be acceptable, fifth- and sixth-order curves were generated to procure the best possible fit. After the best fit curves were found, equations were written for each curve. As can be seen in the figure, this technique resulted in excellent curve fits.

A computer program that back-calculates distress densities for any deduct value was developed using the AC deduct curve equations. Densities were determined for all AC distress type/severity level combinations at various deduct values. An example of a portion of the output from the program is shown in Table 4.

Initial density ranges based on the deduct value concepts presented above were developed based on input from several pavement engineers. A low-density range was defined for distress type/severity level combinations corresponding to a deduct value less than or equal to 10 points. Distress type/severity level combinations with a range of deduct values between 10 and 20 points made up the medium-density classification range, and distress combinations that resulted in deduct values greater than or equal to 20 points were assigned to the high-density classification range. The resulting low-, medium-, and high-density ranges are shown in Tables 5, 6, and 7 for low-, medium-, and high-severity asphalt concrete distress types, respectively. Future research should include obtaining the opinions of additional pavement engineers for modifications to the initial density ranges. In areas where PCI deterioration rates vary from the average rate because of climatic or other conditions, the density range tables can easily be designed to suit local conditions.

To use the tables, each distress type/severity level identified in the condition survey is located in the appropriate severity level table. From these tables, corresponding density classifications

TABLE 4 PAVER DISTRESS DENSITY/DEDUCT VALUES

Distress Type	Severity Level	Density (%)
Alligator Cracking	Low	0.28913
Bleeding	Low	16.91303
Bleeding	Medium	2.03118
Bleeding	High	0.94241
Block Cracking	Low	5.49324
Block Cracking	Medium	1.96720
Block Cracking	High	0.86778
Bumps and Sags	Low	0.69500
Corrugation	Low	2.85177
Corrugation	Medium	0.10000
Depression	Low	1.85847
Edge Cracking	Low	2.80141
Edge Cracking	Medium	0.27842
Jt Reflection Cracking	Low	2.28622
Jt Reflection Cracking	Medium	0.73506
Jt Reflection Cracking	High	0.20625

Note: Distress densities correspond to a deduct value of 5.00.

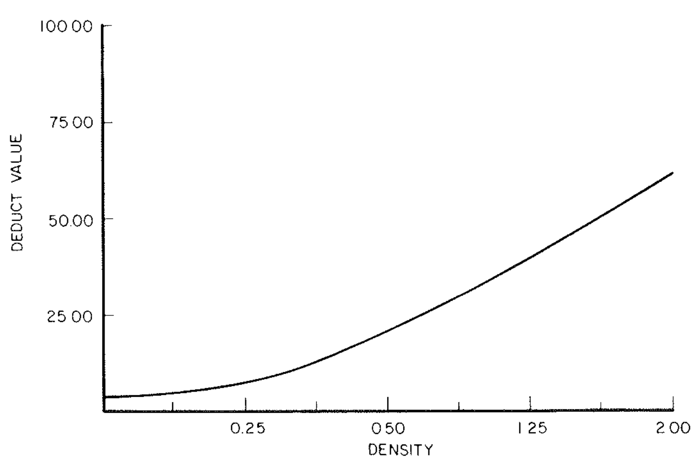

FIGURE 5 Fourth-order fit curve for low-severity alligator cracking.

TABLE 5 DENSITY RANGES FOR LOW-SEVERITY DISTRESSES

Distress Type	Low Density	Medium Density	High Density
Alligator Cracking	< 1	1 - 3	> 3
Bleeding	< 38	>38	No Data
Block Cracking	< 14	14 - 48	> 48
Bumps and Sags	< 2	2 - 4	> 4
Corrugation	< 7	7 - 20	> 20
Depression	< 5	5 - 11	> 11
Edge Cracking	< 9	>9	No Data
Jt. Reflection Cr	< 6	6 - 18	> 18
Lane/Shoulder Dropoff	< 8	>8	No Data
L/T Cracking	< 5	5 - 14	> 14
Patch/Utility Cut	< 5	5 - 15	> 15
Polished Aggregate	< 40	>40	No Data
Potholes	< 0.05	0.05 - 0.10	> 0.10
RR Crossing	< 8	8 - 50	> 50
Rutting	< 1	1 - 5	> 5
Shoving	< 3	3 - 10	> 10
Slippage Cracking	< 2	2 - 6	> 6
Swell	< 7	7 - 30	> 30
Weathering & Raveling	< 32	>32	No Data

Note: Low severity distress (% distress density). Jt Reflection Cr = joint reflection cracking; L/T Cracking = longitudinal/transverse cracking; RR = railroad.

TABLE 6 DENSITY RANGES FOR MEDIUM-SEVERITY DISTRESSES

Distress Type	Low Density	Medium Density	High Density
Alligator Cracking	< 0.20	0.20 - 1.0	> 1
Bleeding	< 6	6 - 24	> 24
Block Cracking	< 5	5 - 16	> 16
Bumps and Sags	< 0.20	0.20 - 0.70	> 0.70
Corrugation	< 0.50	0.50 - 2.0	> 2
Depression	< 2	2 - 6	> 6
Edge Cracking	< 2	2 - 6	> 6
Jt Reflection Cr	< 2	2 - 4	> 4
Lane/Shoulder Dropoff	< 5	5 - 10	> 10
L/T Cracking	< 1	1 - 4	> 4
Patch/Utility Cut	< 1	1 - 4	> 4
Polished Aggregate	< 40	> 40	No Data
Potholes	< 0.02	0.02 - 0.04	> 0.04
RR Crossing	< 2	2 - 4	> 4
Rutting	< 0.3	0.30 - 1.0	> 1
Shoving	< 1	1 - 3	> 3
Slippage Cracking	< 1	1 - 2	> 2
Swell	No Data	< 3	> 3
Weathering & Raveling	< 2	2 - 12	> 12

Note: Medium severity distresses (% distress density).

are assigned based on the total quantity of the particular distress type/severity level combination tabulated for the section. Each density classification is then located in a density/severity classification code table such as the one shown in Table 8. This table assigns a number from 1 to 9, which corresponds to a possible preventive maintenance strategy, as explained in the next step.

For example, if a distress survey on one section indicates that there is 5 percent low-severity alligator cracking and 3 percent medium-severity edge cracking present, density classifications of high and medium would be assigned from Tables 5 and 6, respectively. Entering Table 8 for the alligator cracking with a high-density classification and low-severity level, gives a density/severity classification code of 3. Repeating the procedure for the medium-severity edge cracking with a medium-density classification gives a density/severity classification code of 5. These values will be used in the next step to determine appropriate preventive maintenance strategies.

Step 4: Generate Preventive Maintenance Strategies

The distress density/severity classification code identified in the previous step for each distress type is entered into an appropriate strategy-selection table. An excerpt from a typical table for primary and secondary roads is shown in Table 9. These tables should be developed for various pavement functional classifications and should include legitimate preventive maintenance strategies. Commonly used strategies for AC pavements typically include crack sealing, chip seals, slurry seals, patching, thin overlays, do nothing, and no appropriate preventive maintenance strategy. The default table is modified according to the parameters established in Step 1 so that a customized recommendation can be made. The alternatives shown in Table 9 were selected by combining the existing procedures for identifying M&R alternatives in the PAVER system (Table 3) with the experienced judgment of pavement engineers.

As a result of this step, appropriate preventive maintenance strategies are specified for each distress type/severity level identified in the latest condition survey. If the selected treatment was excluded from consideration in Step 1, it should now be upgraded to a treatment defined within the established parameters. If, for example, a chip seal is identified as the recommended strategy for a particular distress type on a high-volume pavement but local policy prevents the use of this type of

TABLE 7 DENSITY RANGES FOR HIGH-SEVERITY DISTRESSES

Distress Type	Low Density	Medium Density	High Density
Alligator Cracking	No Data	< 0.5	> 0.5
Bleeding	< 3	3 - 8	> 8
Block Cracking	< 2	2 - 5	> 5
Bumps and Sags	No Data	< 0.1	> 0.1
Corrugation	< 0.1	0.1 - 0.2	> 0.2
Depression	No Data	< 2	> 2
Edge Cracking	< 0.6	0.6 - 2.0	> 2
Jt Reflection Cr	< 0.5	0.5 - 2.0	> 2
Lane/Shoulder Dropoff	< 2	2 - 5	> 5
L/T Cracking	< 0.4	0.4 - 1.0	> 1
Patch/Utility Cut	< 0.3	0.3 - 1.0	> 1
Polished Aggregate	< 40	> 40	No Data
Potholes	No Data	No Data	> 0.01
RR Crossing	No Data	< 1	> 1
Rutting	< 0.2	0.2 - 0.5	> 0.5
Shoving	< 0.2	0.2 - 1.0	> 1.0
Slippage Cracking	< 0.4	0.4 - 1.0	> 1.0
Swell	No Data	No Data	> 1
Weathering & Raveling	< 0.2	0.2 - 2.0	> 2

Note: High severity distresses (% distress density).

TABLE 8 DENSITY/SEVERITY CLASSIFICATION CODES

		DISTRESS DENSITY		
		L	M	H
DISTRESS SEVERITY	L	1	2	3
	M	4	5	6
	H	7	8	9

TABLE 9 EXCERPT FROM STRATEGY SELECTION TABLE: PRIMARY AND SECONDARY ROADS

DISTRESS TYPE: ALLIGATOR CRACKING	
Classification Code	Preventive Maintenance Strategy
1	DO NOTHING
4,7	PATCHING
2,3,5,6	THIN OVERLAY
8,9	NONE PREVENTATIVE

treatment, the recommended strategy should be upgraded to a thin overlay (or to the appropriate treatment, as identified in Step 1).

Using the same example as in the previous step, and applying the recommendations found in Table 9, the suggested strategy for the alligator cracking would be Thin Overlay. Similar strategy tables would exist for all other distress types.

Step 5: Determine Dominant Strategies

After all possible preventive maintenance alternatives have been identified for a section, one dominant strategy needs to be selected. This step should include the formation of a flow chart, which includes all possible combinations that could be selected for a section identified as a preventive maintenance candidate. The flowchart must distinguish which alternatives override others and which combinations give an indication that preventive maintenance may not be appropriate, and a project level investigation should be performed. An example of a flowchart is shown in Figure 6.

The dominant strategy selected should also include any localized corrective treatments such as crack sealing or patching, which need to be applied before the recommended alternative is applied. Quantities of work should also be determined for the calculation of costs as described in a later step.

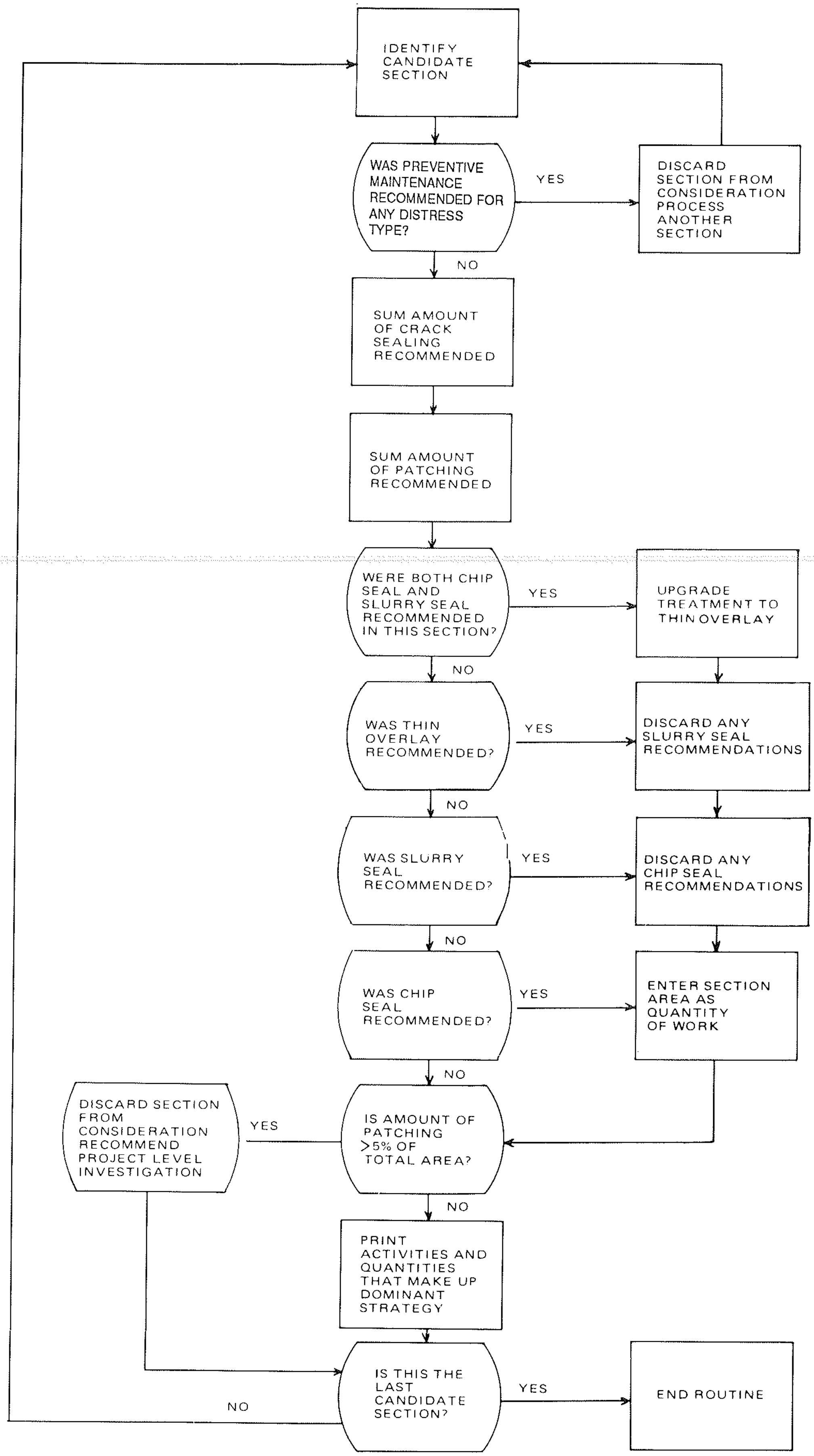

FIGURE 6 Dominant strategy selection flowchart.

PCI \ PAVEMENT RANK	PRIMARY	SECONDARY	TERTIARY
90 - 100	4	7	9
80 - 89	2	5	8
70 - 79	1	3	6

FIGURE 7 Preventive maintenance prioritization scheme.

Step 6: Prioritize Strategies

Once the final decision has been made about the appropriate dominant strategy, the agency must devise a ranking scheme so that the most crucial projects are funded first. Typically, parameters used in the decision process include some indicator of condition and functional classification of the pavement. A sample prioritization scheme is shown in Figure 7. This scheme places the emphasis on applying preventive maintenance treatments to eligible sections with the highest functional classification (primary) and worst condition ($70 < PCI < 80$). Any remaining money is then allocated to candidate sections on primary roads with PCIs between 80 and 90. Additional projects continue to be scheduled in order of priority until all preventive maintenance funding is depleted.

Step 7: Calculate Costs

Based on the costs' input in Step 1, an optimal preventive maintenance budget should be prepared that determines the costs associated with applying the selected treatment to each candidate section. These costs will be used in the next step to determine actual preventive maintenance projects.

Step 8: Generate Outputs

The results of the previous seven steps are summarized and presented in the form of a preventive maintenance report outlining work to be performed and budget estimates. By combining the prioritized work list obtained in Step 6 and the cost figures obtained in Step 7 with the actual amount of dollars available, a list of actual preventive maintenance projects will be obtained.

SUMMARY

A Pavement Management System is an important tool for pavement engineers in maintaining pavements in the best possible condition for the lowest cost. By performing pavement repairs while the pavements are still in good condition, costs can be reduced by a factor of 4 to 5. The application of preventive maintenance treatments can play an important role in prolonging pavement service life by deterring pavement deterioration. This paper presented the development of a preventive maintenance algorithm for use in Pavement Management Systems and introduced a new concept in determining distress density limits for the recommendation of preventive maintenance treatments.

The preventive maintenance algorithm outlined in this paper consists of several fundamental steps. First, parameters are defined. This includes identifying which treatments are to be considered and the unit costs associated with these activities, in addition to the minimum pavement condition above which a preventive maintenance strategy is recommended. Eligible sections are identified, and distress density classifications are determined.

Unlike other preventive maintenance algorithms, which base density ranges on subjective judgments, a procedure is described in this paper that was developed at USA-CERL that relates distress density directly to PCI deduct values. The advantage to this approach is that the amount of deterioration that each distress type/severity level combination causes on the pavement is derived from an objective rating scale that was used to determine PCI deduct values.

After candidate sections have been identified and density classifications have been assigned, preventive maintenance treatments are recommended. A dominant strategy is selected from all possible treatments for a section, and costs are calculated. Based on the agency prioritization scheme and the budget available, actual preventive maintenance projects can be identified.

The preventive maintenance concepts outlined in this paper are applicable to both AC and PCC pavements. They are designed to be flexible enough to allow for local policies and conditions. In addition, they can be easily expanded to include environmental or geographical factors and additional preventive maintenance treatments at a later date.

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Publication of this paper sponsored by Committee on Pavement Management Systems.