COMPONENTS OF A PAVEMENT MAINTENANCE MANAGEMENT SYSTEM

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This paper discusses the important components of a rational pavement maintenance management system: (1) pavement network identification, (2) pavement inspection and rating, (3) pavement condition evaluation and determination of maintenance and rehabilitation (M&R) requirements, (4) M&R priorities, (5) M&R consequence models, (6) life cycle costing, and (7) data management and report generation. Each component is illustrated by examples from a working system developed for the U.S. Air Force and Army for pavement maintenance management of airfields and roads. The paper is intended to serve as a guideline for those pavement agencies that want to develop or improve their pavement maintenance management system.

Most of the in-service pavements in the United States were built many years ago, and only very limited amounts of new pavements are being constructed now. These older pavements, which deteriorate more quickly than new roads, increase user costs through vehicle deterioration, delay in travel time, and energy consumption, and necessitate the unplanned spending of taxpayers' money for their repair. Unfortunately, the availability of maintenance and rehabilitation (M&R) funds is not keeping pace with the rate of pavement deterioration. The national backlog of needed M&R for state highways is estimated to be in the billions of dollars. A great deal of money is spent annually on emergency repair, such as filling of potholes. Since many emergency repairs are temporary and must be repeated periodically, much more money is spent over the pavement life than is necessary. Therefore, there is an urgent need for pavement agencies to adopt rational pavement maintenance management systems. The objectives and/or benefits to be derived include:

1. Knowledge of the existing pavement and of the condition and health of the pavement system.
2. Rational determination of M&R needs by setting performance standards.
3. The ability to generate or develop a list of priority M&R needs on demand.
4. Availability of information, including maintenance cost data.
5. Ability to answer "what if" questions dealing with the consequences of implementing various M&R alternatives.
6. Ability to perform life cycle costing and to determine the consequences of various M&R alternatives.
7. Ability to develop long-range M&R plans.
8. Ability to optimize a given M&R budget.
9. Establishment of or improvement of communications among the various management levels dealing with M&R.

This paper presents components of a comprehensive pavement maintenance management system; these components are described through the pavement maintenance management system for airfields and roads developed for the U.S. Air Force and Army. The system components include (1) identifying the pavement network, (2) inspecting and rating pavements, (3) evaluating pavement condition and determining M&R requirements, (4) establishing M&R priorities, (5) determining the consequences of various M&R alternatives, (6) performing life cycle costing for selection of cost-effective M&R strategies, and (7) managing data and generating reports. The following sections describe each component.

Network Identification

Network identification is the process of dividing the pavement network into manageable sections (also called segments or features) for inspection and for determining M&R needs and priorities. Each pavement section should be uniform in structural composition, construction history, functional classification, traffic, and condition. A pavement "branch" (also called a "facility," e.g., a given runway or highway) may consist of one or more sections.

Each section is given an identification number within its branch. The location of a section (beginning and end) can be identified on a map, for example, by arrows. On computer output, section locations can be identified by mileposts, existing physical features such as rivers or bridges, or intersection with other pavements. For example, in Figure 1 (1) the location of section number 3 of Washington Blvd. is defined from the south end of

Figure 1. Example output of Inventory Report of the Army system.

```
 CALL,REPORT,INV
 09.48.10. TYPE GENERATE COMMAND THEN TYPE ";EXIT;"
I>GENERATE ALL WHERE BRANCH NUMBER EQ IWASH;EXIT;

REPORT DATE-  06/24/80

                              INVENTORY
                     NON-FAMILY HOUSING PAVEMENTS

                             SURF    BRANCH          PAVEMENT        AREA
                             TYPE     USE              RANK          (SY)
-----------
IWASH WASHINGTON BLVD
      SECTION 01              AC    ROADWAY          PRIMARY         5555
      FROM- N EDGE OF GREEN
      TO-   N EDGE OF NEIL

      SECTION 02              AC    ROADWAY          PRIMARY        11944
      FROM- N EDGE OF NEIL
      TO-   S EDGE OF FIRST

      SECTION 03              AC    ROADWAY          PRIMARY         4706
      FROM- S EDGE OF FIRST
      TO-   S EDGE OF SIXTH
                                             TOTAL BRANCH AREA      22205

         TOTAL AREA OF SELECTED NON-FAMILY HOUSING PAVEMENTS        22,205

* REPORT COMPLETE
```

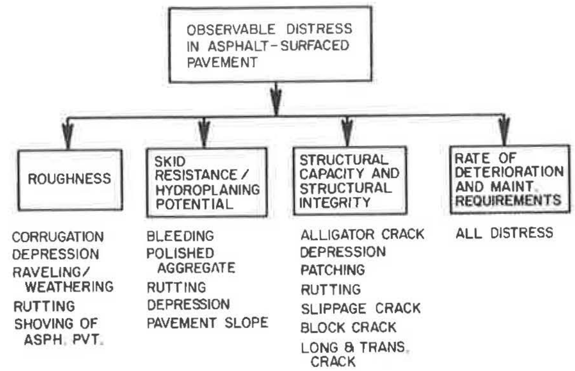
First Street to the south end of Sixth Street. This figure is an example output of a branch inventory obtained from the Army system.

Pavement Inspection and Rating

It is commonly recognized (2, 3, 4) that a rational pavement evaluation requires analysis of pavement roughness (ride), skid, structural capacity, and distress. Different agencies use different equipments, methods, and frequencies to measure these indicators. For example, the U.S. Air Force uses a Laser Profilometer to measure roughness and the Diagonal Braked Vehicle and Mu-Meter to measure skid. In addition, several structural capacity evaluation teams core pavements, determine thicknesses, and determine allowable aircraft loads for each pavement section. Other highway agencies use the Mays Ride Meter to measure ride, a towing vehicle to measure skid, and a Road Rater or Dynaflect to measure structural capacity.

However, more than ever before, the importance of distress measurement and analysis is being emphasized by many Federal and state agencies which are leaders in pavement maintenance management, e.g., the U.S. Air Force (5), California (6), Arizona (7), Washington (8), Ontario (9), and Texas (10). The degree of pavement distress relates directly to needed maintenance, and indirectly measures the other pavement functional indicators, as illustrated for asphalt pavements in Figure 2 (11). Some agencies rely only on the analysis of individual distresses, such as alligator cracking and raveling, to determine the primary cause of pavement deterioration, e.g., load, climate, materials, construction quality control. Other agencies use an index based on weighted distress to serve as a composite pavement condition index. One of the earliest indices used was the State of Washington's Pavement Final Rating; the most recent development in this area has been the U.S. Air Force and Army Pavement Condition Index (PCI). The PCI has been formally adopted worldwide by the Air Force and other agencies, such as the Federal Aviation Administration, and various state aeronautic departments are now evaluating and adopting it. The U.S. Army is currently evaluating the PCI for roads, which was developed after the one for airfields, for implementation.

Figure 2. Relationship of observable distress in asphalt-surfaced pavements to various pavement condition indicators.



The PCI agrees closely with the collective judgment of experienced pavement maintenance engineers. It provides (1) a standard method for rating the structural integrity and operational surface condition of pavement sections, (2) a method for determining M&R needs and priorities by comparing the condition of different pavement sections, and (3) a method of determining pavement performance from accumulated data. The PCI, which measures pavement structural integrity and surface operational condition on a scale from 0 to 100 (Figure 3) (5), is based on measured pavement distress types, severity, and amount of distress obtained during pavement inspection.

To determine the PCI, a pavement section is first divided into inspection units called sample units. For example, for asphalt roads, a sample unit is approximately 230 m^2 (2500 sq ft) (e.g., 7.6 m [25 ft] wide x 30 m [100 ft] long). The number of sample units to be inspected (n) is determined from Figure 4 (11) as a function of the total number of units in the section (N) and the standard deviation of the PCI (σ) between sample units in the section. The location of units to be inspected is determined using either the "stratified-random" or "systematic-random" techniques (12).

The PCI method uses weighted (deduct) values that are functions of the types, severities, and densities of visible distress. The current PCI of a given sample unit is determined by adding the deduct values for observed distresses in a given sample unit, adjusting the sum, and then subtracting the sum from a maximum possible PCI.

Figure 3 summarizes the steps for computing the PCI for a pavement section. It should be emphasized that inspection procedures closely follow methods outlined in distress manuals (5, 11, 13) developed over several years of continuous field evaluation, revision, and improvement.

Pavement Condition Evaluation and Determination of M&R Requirements

Figure 5 is a flow chart summarizing the process for determining M&R requirements. This process is greatly expedited in an automated pavement maintenance management environment. Following is a brief description of the logical steps of this process:

Figure 3. Steps for determining PCI of a pavement section.

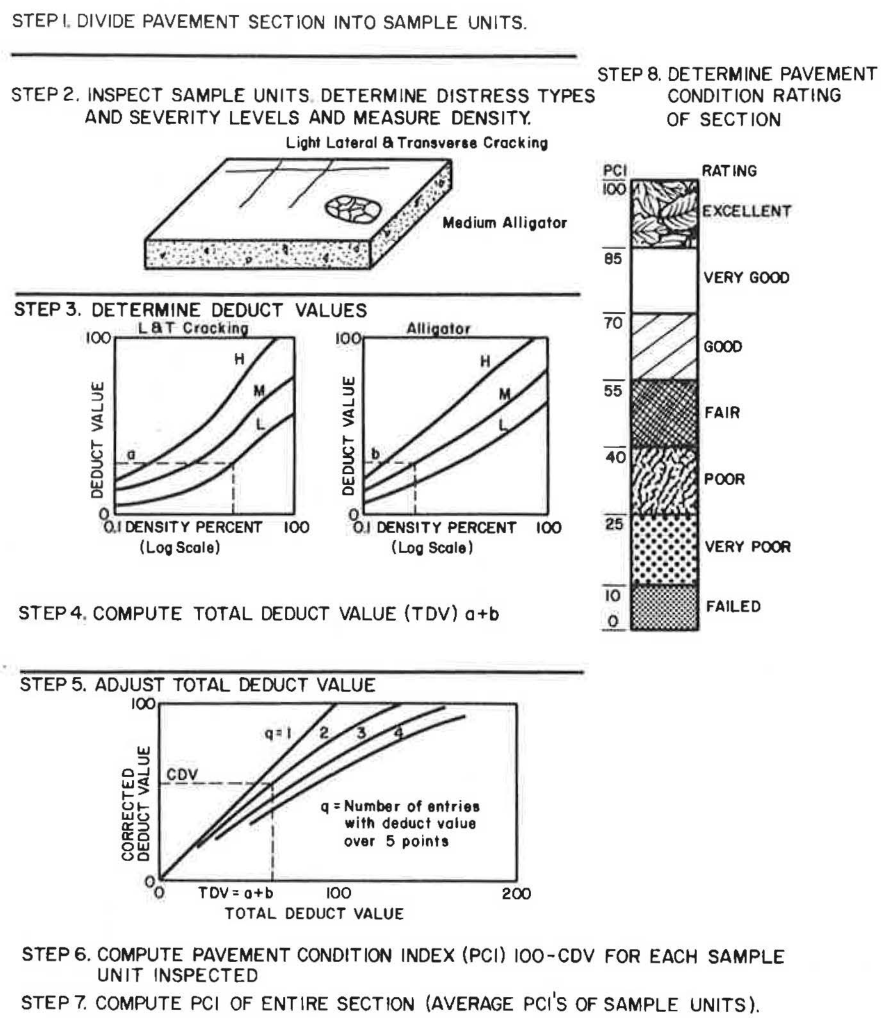


Figure 4. Determination of minimum number of sample units to be surveyed for 95 percent confidence that the error in PCI of section is within ±5 points.

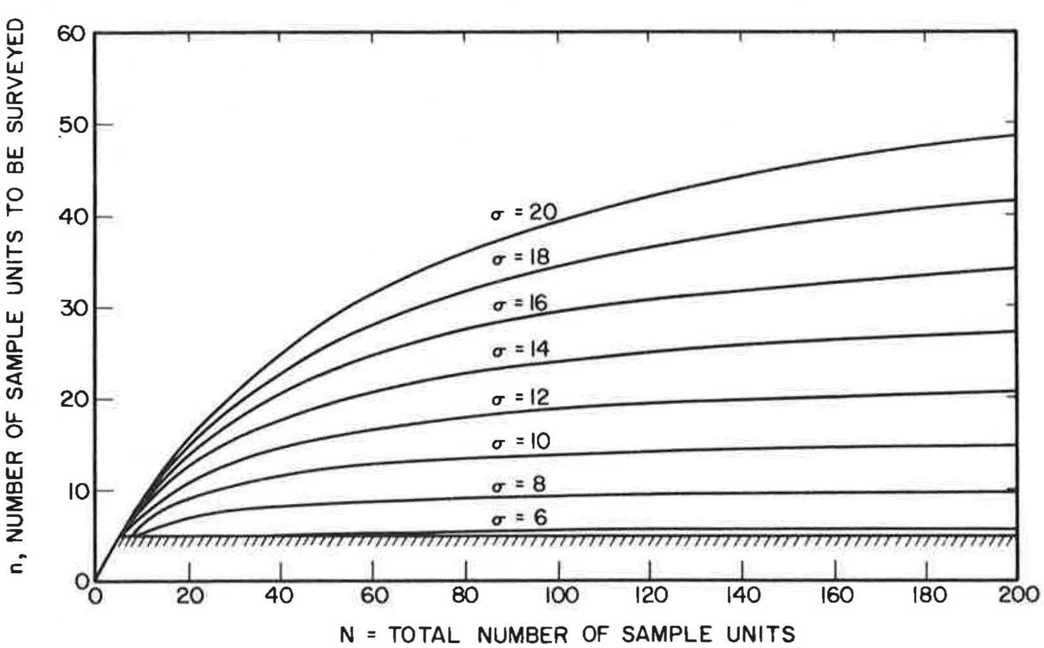


Figure 5. Flow chart summary of the process of determining M&R requirements.

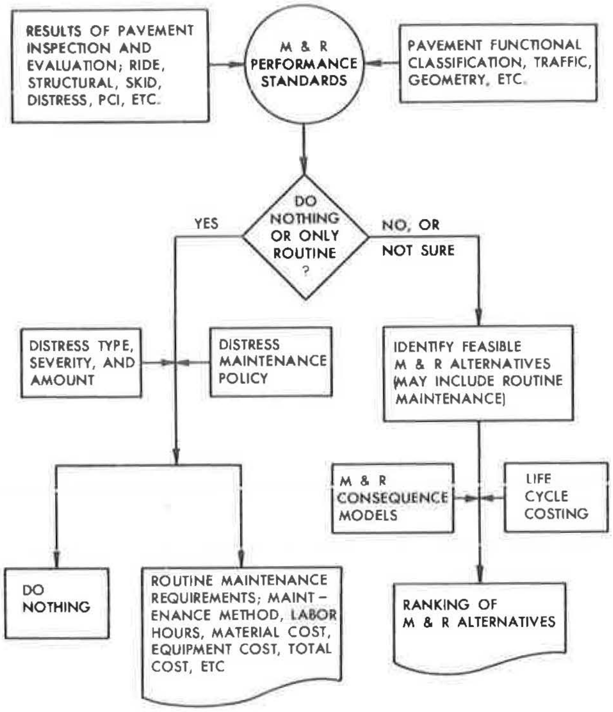
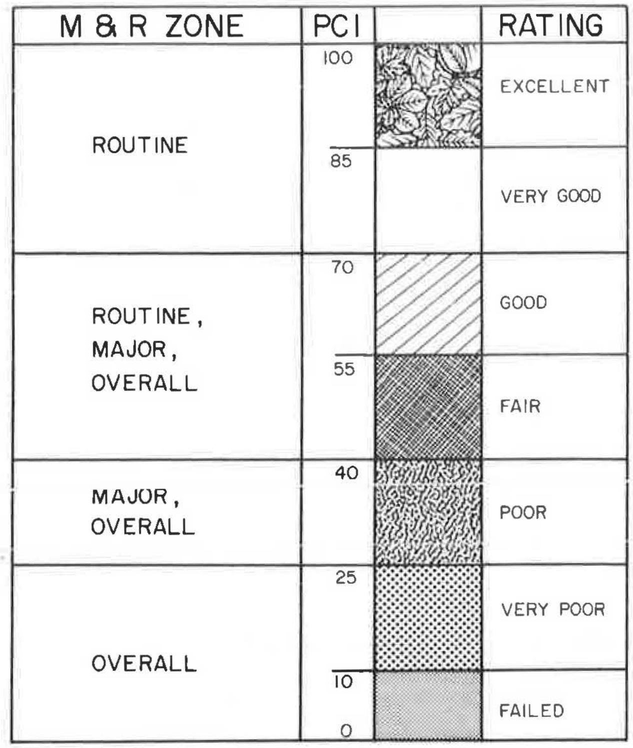


Figure 6. Correlation of M&R zones with PCI and condition rating.



Decision to "Do Nothing" or to Perform "Only Routine" Maintenance Within 1 to 2 Years

The inputs needed to make this decision are taken from the most recent pavement inspection and evaluation, and from other relevant pavement information, such as functional classification and traffic. The decision is based on the agency's performance standards. Performance standards may consist of limits on ride, skid number, and individual distress densities (% area) or composite pavement condition. Figure 6 (14) shows an example of the PCI-based portion of the performance standards used by the Air Force. Other parts of the performance standards include the results of pavement evaluation shown in Figure 7 (12).

Determination of Routine (Including Preventive) Maintenance Requirements

The healthier the pavement network, the more pavement sections would be treated under this step, rather than considering major or overall rehabilitation. The primary input for this step is the type, severity, and amount of distress. Tables such as Table 1 (12), which summarizes recommended maintenance methods for various asphalt road distresses, have been useful to field maintenance engineers. For pavement agencies with automated systems, a distress maintenance policy, as shown in Table 2, can be stored in the computer. At the user's request, a specially designed computer program combines the maintenance policy with distress information for selected pavement sections; routine maintenance requirements are then generated, as shown in Figure 8 (1).

Figure 7. Pavement section condition evaluation summary.

PAVEMENT EVALUATION SUMMARY

1. PCI : ______ RATING : ______ M&R ZONE : ______
2. PCI VARIATION : UNIFORM LOCALIZED SYSTEMATIC
3. PCI RATE OF DETERIORATION
   a. LONG-TERM : LOW NORMAL HIGH
   b. SHORT-TERM : LOW NORMAL HIGH
4. DISTRESS EVAL. : CAUSE PERCENT DEDUCT
   LOAD ______
   CLIMATE ______
   OTHER ______
5. STRUCTURAL CAPACITY DEFICIENCY : NO YES
6. SURFACE ROUGHNESS : MINOR MODERATE MAJOR
7. SKID POTENTIAL : NONE NOT DEFINED EXISTS HIGH
8. PREVIOUS MAINT : LOW NORMAL HIGH
9. EFFECT ON MISSION : ______

Table 1. Asphalt concrete pavement distress types and M&R alternatives.

	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*							*apply shoulder seal, e.g., agg. seal coat
8	Joint Reflective Cracking	L	L,M,H	H								
9	Lane/ Shoulder Drop-Off	L									M,H*	*level off shoulder and apply agg. 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.

Table 2. Example distress maintenance policy output.

REPORT DATE- 06/25/80

MAINTENANCE POLICY

DISTRESS TYPE	SEV	REPAIR TYPE	MTL CODE	REPAIR UNIT	LABOR HR/UNIT	UNIT COSTS($) LABOR	MTL	EQUIP	TOTAL
CORNER SPALLING									
	H	SHALLOW PATCH	110	SF	.300	4.790	.860	1.010	6.660
	M	SHALLOW PATCH	110	SF	.300	4.790	.860	1.010	6.660
DURABILITY CR									
	H	SLAB REPLACING	110	SY					60.000
	M	DEEP PATCH	110	SF	.600	9.580	1.720	2.020	13.330
FAULTING									
	H	GRINDING		SF					2.000
	M	GRINDING		SF					2.000
JOINT SPALLING									
	H	SHALLOW PATCH	110	SF	.300	4.790	.860	1.010	6.660
	M	SHALLOW PATCH	110	SF	.300	4.790	.860	1.010	6.660
JT SEAL DAMAGE									
	H	JOINT FILLING	171	LF	.030	.580	.070	.100	.750
LG PATCH/UTIL									
	H	DEEP PATCH	110	SF	.600	9.580	1.720	2.020	13.330
	M	DEEP PATCH	110	SF	.600	9.580	1.720	2.020	13.330
PUNCHOUT									
	H	DEEP PATCH	110	SF	.600	9.580	1.720	2.020	13.330
	M	DEEP PATCH	110	SF	.600	9.580	1.720	2.020	13.330
SMALL PATCH									
	H	SHALLOW PATCH	110	SF	.300	4.790	.860	1.010	6.660

```
* REPORT COMPLETE
* PAVER READY.....
C>CALL,REPORT,POLICY
 07.14.44. TYPE GENERATE COMMAND THEN TYPE ";EXIT;"
I>GENERATE ALL WHERE DIST CODE LT 20;EXIT;
```

Note: 1 SF - .0920 m^2; 1 LF = .3048 m.

Figure 8. Report listing local maintenance requirements of sections.

MAINTENANCE AND REPAIR GUIDELINES

BRANCH NAME - CENTER AVE SLAB LENGTH - 20 LF
BRANCH NMBR - ICENT SLAB WIDTH - 11 LF
SECTION NMBR - 01 NMBR. OF SLABS - 76

INSPECTION DATE - 06/18/79 SECTION PCI - 36

DISTRESS TYPE	DIS SEV	DIST-QTY WORK-QTY	WORK TYPE	MAT'L CODE	LABOR HOURS	LABOR COST$	MAT'L COST$	EQUIP COST$	TOTAL COST$
DURABILITY CR	L	3 SLAB							
			--- NO MAINTENANCE POLICY AVAILABLE ---						
DURABILITY CR	M	10 SLAB							
		250 SF	DEEP PATCH	110	150.0	2394	429	504	3332
FAULTING	L	2 SLAB							
			--- NO MAINTENANCE POLICY AVAILABLE ---						
FAULTING	M	1 SLAB							
		11 SF	GRINDING	***	0.0	0	0	0	22
FAULTING	H	1 SLAB							
		11 SF	GRINDING	***	0.0	0	0	0	22
JT SEAL DAMAGE	H	76 SLAB							
		3116 LF	JOINT FILLING	171	93.5	1807	218	311	2337
LG PATCH/UTIL	L	3 SLAB							
			--- NO MAINTENANCE POLICY AVAILABLE ---						
LG PATCH/UTIL	M	1 SLAB							
		55 SF	DEEP PATCH	110	33.0	526	94	111	733
LG PATCH/UTIL	H	7 SLAB							
		385 SF	DEEP PATCH	110	231.0	3688	662	777	5132
SMALL PATCH	L	6 SLAB							
			--- NO MAINTENANCE POLICY AVAILABLE ---						
SMALL PATCH	M	7 SLAB							
			--- NO MAINTENANCE POLICY AVAILABLE ---						
SMALL PATCH	H	19 SLAB							
		76 SF	SHALLOW PATCH	110	22.8	364	65	76	506
POLISHED AGG	N	7 SLAB							
			--- NO MAINTENANCE POLICY AVAILABLE ---						
PUNCHOUT	M	1 SLAB							
		44 SF	DEEP PATCH	110	26.4	421	75	88	586
PUNCHOUT	H	1 SLAB							
		44 SF	DEEP PATCH	110	26.4	421	75	88	586
SHRINKAGE CR	N	9 SLAB							
			--- NO MAINTENANCE POLICY AVAILABLE ---						
CORNER SPALLING	M	6 SLAB							
		6 SF	SHALLOW PATCH	110	1.8	28	5	6	39
CORNER SPALLING	H	6 SLAB							
		9 SF	SHALLOW PATCH	110	2.7	43	7	9	59
JOINT SPALLING	L	4 SLAB							
			--- NO MAINTENANCE POLICY AVAILABLE ---						
JOINT SPALLING	M	15 SLAB							
		90 SF	SHALLOW PATCH	110	27.0	431	77	90	599
JOINT SPALLING	H	29 SLAB							
		478 SF	SHALLOW PATCH	110	143.6	2292	411	483	3186
POPOUTS	N	11 SLAB							
			--- NO MAINTENANCE POLICY AVAILABLE ---						
				TOTAL	758.1	12415	2118	2543	17139

Determination of Feasible M&R Alternatives

If the decision about whether to perform only routine maintenance is not clear, then other feasible M&R should be identified. Feasible M&R alternatives are determined based on the results of the evaluation shown in Figure 7. In this figure, the PCI is used to determine whether there are localized or systematic variations in the pavement, and to determine the pavement's long- and short-term deterioration rates. The distress information is used to compute the different percentage effects of loads, climate, and other factors on pavement condition. Other variables included in the procedure are load capacity, roughness, skid-hydroplaning potential, and previous maintenance.

For example, if none of the evaluation items in Figure 7 is exceeded (e.g., rate of deterioration is low, load-carrying capacity is adequate), then only routine maintenance should be considered. On the other hand, if skid is the only item that is deficient, then feasible alternatives may include surface grooving, recycling, overlay, or application of a surface friction course.

Ranking of M&R Alternatives for a Given Pavement Section

The ranking of feasible M&R alternatives for any pavement section is based on how each alternative will affect future pavement performance and associated cost. Consequence models and life cycle costing are described in subsequent sections of this paper.

M&R Priorities

Establishment of an M&R priority list is usually the first specific payoff that managers expect from a pavement maintenance management system. The criteria for establishing priorities for pavement sections requiring routine maintenance are different from those used for sections needing major or overall M&R.

M&R priorities for sections requiring routine maintenance are functions of individual distress types and severities. Distresses having a large negative effect on the pavement's operational condition are given the highest priority, e.g., medium- and high-severity joint spalling, potholes, bumps, cracking. Priorities for sections requiring major or overall M&R are usually based on pavement condition and functional class; the PCI is very useful for determining these criteria. Figure 9 (1), an example output from the Army PCI system, lists primary roads with PCIs of less than 70 in increasing order of the PCI. This system can generate a separate list for other functional classes, such as secondary or tertiary pavements.

M&R Consequence (Prediction) Models

Prediction models are a series of equations with the overall objective of predicting pavement performance for various M&R alternatives, including a "do nothing" alternative. Equation 1 shows the general mathematical functional relationship of such models. Pavement condition indicators (the left-hand side of equation 1) predicted by the models include ride, skid, cost, deflection, expected life of specific maintenance activities such as joint seal, individual distress types such as cracking and

Figure 9. Report listing sections in order of increasing PCI.

```
 CALL,REPORT,PCI
09.32.06. TYPE GENERATE COMMAND THEN TYPE ";EXIT;"
I>GENERATE ALL WHERE PAVEMENT RANK EQ PRIMARY AND PCI LT 90;EXIT;

REPORT DATE-  06/24/80                         PCI REPORT

BRANCH          BRANCH    SECTION                        SURFACE     SECTION   PAVEMENT
NUMBER           USE      NUMBER    PCI     RATING         TYPE      AREA/SY     RANK

ICENT          ROADWAY       01     36       POOR          PCC          1858    PRIMARY
T8A            TAXIWAY       01     78    VERY GOOD        PCC          8542    PRIMARY
55512          ROADWAY       04     80    VERY GOOD        PCC          5333    PRIMARY
55512          ROADWAY       01     81    VERY GOOD        AC           4533    PRIMARY
55512          ROADWAY       02     85    VERY GOOD        AC           3466    PRIMARY
T14A           TAXIWAY       01     86    EXCELLENT        PCC         25139    PRIMARY
T9A            TAXIWAY       01     88    EXCELLENT        PCC         34722    PRIMARY
AIB            APRON         01     89    EXCELLENT        PCC        166667    PRIMARY

* REPORT COMPLETE
C>
```

Figure 10. Example output of the PCI consequence models.

```
 ENTER PAVEMENT ID
I>RUNWAY 5/23
 ENTER PAVEMENT TYPE. AC OR PCC (A/P)
I>AC
 HAS PCI BEEN PREVIOUSLY DETERMINED? (Y/N)
I>N
 ENTER TIME IN YEARS BETWEEN ORIGINAL CONSTRUCTION [AGECOL]
 AND LAST OVERLAY (0 IF NO OVERLAY)
I>0
 ENTER TOTAL AC THICKNESS IN INCHES INCLUDING OVERLAYS [TB]
I>4
 ENTER TOTAL PAVEMENT THICKNESS ABOVE SUBGRADE [TSG]
I>16
 ENTER CBR OF BASE [CBR-B]
I>60
 ENTER CBR OF SUBGRADE [CBR-SG]
I>10
 ENTER AIRCRAFT ID (OR "HELP") [ID]
I>HELP
 T38 F4 C130 DC9 B737/200 B727/200 B707/320B C141 B747F C5A B52
I>B727/200

 ACCEPT,CHANGE,DISPLAY? (A/C/D)
I>A
 ENTER PREDICTION AGES SEPARATED BY COMMAS
I>0,10,25


   RUNWAY 5/23

   B727/200 AIRCRAFT ID
         0.0 AGE BETWEEN CONSTRUCTION/OVERLAY OF PAVEMENT AND LAST OVERLAY
         4.0 TOTAL AC THICKNESS IN INCHES INCLUDING OVERLAYS
        16.0 TOTAL PAVEMENT THICKNESS ABOVE SUBGRADE
        60.0 CBR OF BASE
        10.0 CBR OF SUBGRADE


    AGE         PCI
    ---         ---
    0.0       100.0
   10.0        67.0
   25.0        17.5


 DO YOU WISH TO DETERMINE THE CONSEQUENCE ON PCI OF CHANGE IN
 AIRCRAFT, OVERLAY, OR NONE? (A/O/N)
I>O
 ENTER AGE TO OVERLAY
I>10
 ENTER OVERLAY THICKNESS
I>3
 ENTER PREDICTION AGES SEPARATED BY COMMAS
I>0,9,10,25


   RUNWAY 5/23

   B727/200 AIRCRAFT ID
         0.0 AGE BETWEEN CONSTRUCTION/OVERLAY OF PAVEMENT AND LAST OVERLAY
         4.0 TOTAL AC THICKNESS IN INCHES INCLUDING OVERLAYS
        16.0 TOTAL PAVEMENT THICKNESS ABOVE SUBGRADE
        60.0 CBR OF BASE
        10.0 CBR OF SUBGRADE

        10.0 AGE OF OVERLAY
         3.0 THICKNESS OF OVERLAY


    AGE         PCI
    ---         ---
    0.0       100.0
    9.0        70.3
   10.0       100.0
   25.0        50.8
```

rutting, and composite pavement condition such as the PCI. Techniques used to develop the models include regression based on in-service data, mechanistic, probabilistic, or any combination of these.

$$\text{Pavement Condition Indicator} = \text{function of [age, pavement structural composition, construction history, traffic, climate, material properties, geometry, and maintenance]} \quad (1)$$

In addition to predicting pavement performance for various M&R alternatives, consequence models provide valuable input to life cycle costing, budgeting, and planning. Also, the predictions can be used to identify the pavement sections that should be scheduled for inspection, and this will reduce inspection costs.

Figure 10 (15) provides example output from the PCI consequence models which are part of the U.S. Air Force's overall pavement maintenance management system; these models have been designed and programmed for interactive use. Figure 11 (1) is an example output of the interactive individual distress prediction model.

Life Cycle Costing

Life cycle costing is useful when comparing various M&R alternatives for a given pavement section. Figure 12 (1) is example output from an interactive life cycle costing program designed for the U.S. Army and Air Force. Factors included in the life cycle costing are initial cost, future M&R costs, interest and inflation rates, analysis period, and salvage value.

Salvage value, as used in this program, is defined as the difference between building a new pavement and the cost of rehabilitation at the end of the analysis period. Alternately, the salvage value is assumed to be zero; however, the M&R cost for the last year in the analysis period should be the cost of the rehabilitation necessary to upgrade the pavement so that its quality is equivalent to that of a new pavement.

Data Management and Report Generation

To use a pavement maintenance management system efficiently, one must be able to store and retrieve data expediently. The U.S. Army and Air Force systems are operated via a disk-sized computer terminal. Data may be added, changed, or deleted by having it keypunched and read in through a card reader or interactively by using the disk-sized terminal. Figure 13 is an example of interactive data update. Information and two types of reports (writer reports and computation reports) are generated through the same terminal.

Writer Reports

These are preformatted reports generated by the data base manager feature called the report writer. The report writer has a built-in capability for sorting through stored information to meet specific user requirements. Such reports include inspection results, lists of pavement sections in an increasing order of the PCI (Figure 9), pavement inventory (Figure 1), pavement structure, work required, and work history. The formats of these reports can be modified or new reports developed in just a few days.

Figure 11. Example output of individual distress prediction program.

```
                    DISTRESS INPUT DATA

        DISTRESS TYPE =        8.
        AGE        =   10.00  YEARS
        L          =    2.05
        M          =    3.40
        H          =     .81
        EARLIEST DISTRESS STARTING TIME =        0.0  YEARS
        LATEST DISTRESS STARTING TIME    =        5.0  YEARS
        DISTRESS AT INITIAL TIME =    .0100
        EARLIEST TIME FROM L TO M        =        0.0  YEARS
        LATEST TIME FROM L TO M          =        5.0  YEARS
        EARLIEST TIME FROM M TO H        =        0.0  YEARS
        LATEST TIME FROM M TO H          =        5.0  YEARS
        MAXIMUM PREDICTION AGE           =       20.0  YEARS


   OPTIMUM VALUES
        INITIAL TIME       =          0.0  YEARS
        TIME FROM L TO M =              1  YEARS
        TIME FROM M TO H =              3  YEARS
              MEAN                 =   16.8417   YEARS
              STANDARD DEVIATION =      4.4615   YEARS
```

YEAR	L+M+H	L	M	H
0	.01	.01	0.00	0.00
1	.02	.01	.01	0.00
2	.05	.02	.02	0.00
3	.10	.05	.05	0.00
4	.20	.10	.09	.01
5	.40	.20	.18	.02
6	.76	.36	.35	.05
7	1.37	.61	.66	.10
8	2.38	1.01	1.17	.20
9	3.94	1.56	1.98	.40
10	6.26	2.32	3.19	.76
11	9.52	3.26	4.89	1.37
12	13.89	4.37	7.15	2.38
13	19.46	5.57	9.95	3.94
14	26.21	6.75	13.20	6.26
15	33.99	7.78	16.69	9.52
16	42.52	8.53	20.10	13.89
17	51.41	8.89	23.06	19.46
18	60.24	8.83	25.20	26.21
19	68.57	8.33	26.25	33.99
20	76.05	7.48	26.05	42.52

Computation Reports

These are special reports that use computer calculations based on data stored in the system and/or data provided by the user. Such reports include M&R requirements (Figure 7), M&R consequence (Figure 10), individual distress prediction (Figure 11), and life cycle costing (Figure 12). Other computation reports can be developed and interfaced with the system as needed.

Conclusions

The components of a comprehensive pavement maintenance management system have been described through an example working system. Pavement maintenance management is an idea which is most timely. At a time when pavements are deteriorating very quickly and maintenance budgets are limited, the benefits of adopting a pavement maintenance management system are numerous. One benefit is having a consistent, rational method of pavement condition rating such as the PCI. Such a rating is an invaluable tool for communication, particularly when justifying M&R requirements to decision-making personnel. In addition, having the capability to perform a comprehensive pavement evaluation that considers condition rating, deterioration rate, structural capacity, and previous maintenance allows rational determination of M&R requirements and avoids over- or under-maintenance of a pavement. An important payoff related to these advantages is the ability to establish an M&R priority list. Such

Figure 12. Example output of the life cycle cost program.

```
                 COMPARISON OF M&R ALTERNATIVES
                           GREEN ST
                          SECTION 04

                                          INFLATION RATE 13.00 PERCENT
ANALYSIS PERIOD - 20 YEARS                INTEREST RATE  11.00 PERCENT

ALTERNATIVE      DESCRIPTION                        NET PRESENT COST
          B      COLD MILL&OVERLAY                            47341.
          C      RECONSTRUCT                                  65575.
          A      2 IN OVERLAY                                115424.
```

DETAILED COMPARISON OF M&R ALTERNATIVES

YEAR	ALT A COST	ALT A PRES COST	ALT B COST	ALT B PRES COST	ALT C COST	ALT C PRES COST
0 (FY80)	15900	15900	22350	22350	36000	36000
1 (FY81)	0	0	0	0	0	0
2 (FY82)	0	0	0	0	0	0
3 (FY83)	0	0	0	0	0	0
4 (FY84)	0	0	0	0	0	0
5 (FY85)	0	0	0	0	0	0
6 (FY86)	0	0	0	0	0	0
7 (FY87)	39900	45212	2000	2266	1000	1133
8 (FY88)	0	0	0	0	0	0
9 (FY89)	0	0	0	0	0	0
10 (FY90)	0	0	0	0	0	0
11 (FY91)	0	0	0	0	0	0
12 (FY92)	0	0	0	0	0	0
13 (FY93)	0	0	0	0	0	0
14 (FY94)	0	0	0	0	0	0
15 (FY95)	0	0	0	0	0	0
16 (FY96)	0	0	0	0	0	0
17 (FY97)	0	0	0	0	0	0
18 (FY98)	0	0	0	0	0	0
19 (FY99)	0	0	0	0	0	0
20 (FY00)	38000	54311	15900	22725	19900	28442
TOTAL	93800	115424	40250	47341	56900	65575
SALVAGE	0	0	0	0	0	0
PRES WORTH		115424		47341		65575

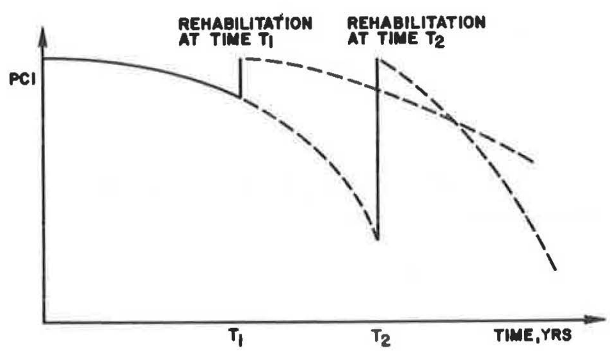
```
DO YOU WISH TO MAKE SAME ANALYSIS
WITH DIFFERENT INTEREST AND INFLATION RATES?(YES/NO)
I>YES
ENTER INTEREST RATE (PERCENT):
I>6
ENTER INFLATION RATE (PERCENT):
I>17
PRINT DETAIL ANALYSIS? (YES/NO)
I>NO
REPORT DATE -  80/06/24.

                 COMPARISON OF M&R ALTERNATIVES
                           GREEN ST
                          SECTION 04

                                          INFLATION RATE 17.00 PERCENT
ANALYSIS PERIOD - 20 YEARS                INTEREST RATE   6.00 PERCENT

ALTERNATIVE      DESCRIPTION                        NET PRESENT COST
          B      COLD MILL&OVERLAY                           140893.
          C      RECONSTRUCT                                 181364.
          A      2 IN OVERLAY                                369309.
```

Figure 13. Example consequence of differing rehabilitation.



a payoff can be realized during the early years of pavement maintenance management implementation.

Probably the greatest benefit of this system is its contribution to the development of M&R consequence models that are based on all available data. With such models, previous M&R decisions and policies can be assessed and future ones improved. Important "what if" questions can be answered. For example, what is the consequence of delaying any project or combination of projects for any period of time in terms of cost and further pavement deterioration (Figure 13)? What is the consequence of allowing heavier traffic to use a specific pavement section (Figure 14)? What is the consequence of applying an asphalt surface treatment instead of overlay or reconstruction (Figure 15)? Another payoff of the consequence models and life cycle costing procedures is the ability to predict and plan future M&R needs and budgets, as well as the ability to optimize a given budget and still obtain maximum benefits.

Although the benefits are overwhelming, the pace of implementing a pavement maintenance management system depends on available money and manpower. However, it should also be realized that overcoming initial obstacles (e.g., resource availability, data credibility, system residence, documentation, interdepartmental communications, training) in implementing such a system is the most difficult step.

Figure 14. Example consequence of change in traffic volume and/or load intensity.

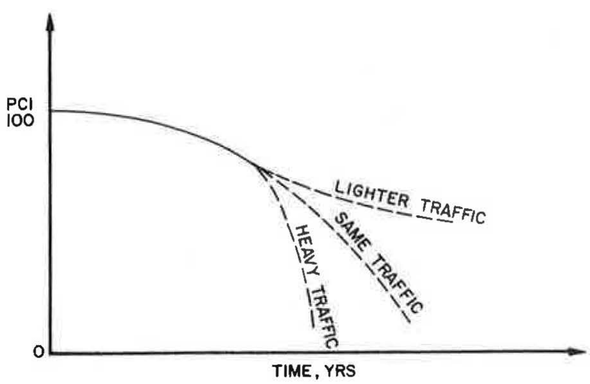
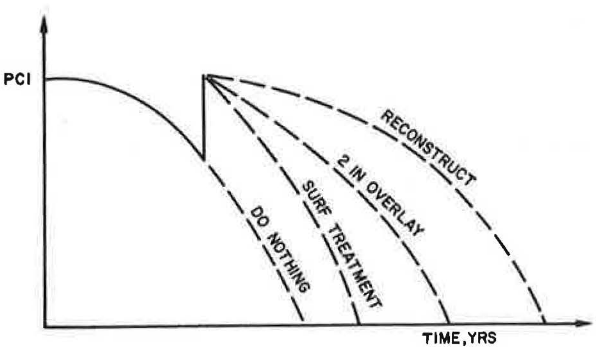


Figure 15. Example consequence of various maintenance and rehabilitation alternatives.



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