Analyzing Consequences of Pavement Maintenance and Rehabilitation Budget Scenarios

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A well-tested procedure for analyzing the consequences of various budget scenarios on pavement condition and backlog of maintenance and rehabilitation is presented. The procedure is part of the Micro PAVER system developed by the U.S. Army Corps of Engineers and distributed by the American Public Works Association. The procedure is based on the critical pavement condition index (PCI) concept. The critical PCI concept is explained, and the development of the work plan is demonstrated.

Local agencies including municipalities, military installations, and airports have long struggled to justify their pavement maintenance and rehabilitation (M&R) budgets. Pavements receive low priority as a budget item, especially when plans for preventive maintenance are made. Tools are needed for pavement managers to be able to demonstrate to local government officials the consequences of various budget scenarios, including the do-nothing option. When nothing is done or not enough money is allocated in the budget, the backlog of M&R increases and the cost of restoring the pavement infrastructure in the future becomes prohibitive.

This paper presents a well-tested procedure for analyzing the consequence of various budget scenarios on pavement condition and backlog of M&R. The procedure is part of the Micro PAVER system developed by the U.S. Army Corps of Engineers and distributed by the American Public Works Association. The procedure is based on the critical pavement condition index (PCI) concept and consists of the following steps:

- Perform a PCI survey on pavement sections in the network.
- Group pavement sections into families and develop a PCI deterioration curve for each family.
- Identify the critical PCI (the PCI below which the condition deteriorates rapidly) for each pavement family.
- Assign an appropriate M&R type to each pavement section for each year in the analysis period.
- Priority rank M&R requirements on the basis of budget limitations.
- Calculate M&R cost, future PCI, and backlog of M&R for each budget scenario.

The following is a description of each of the steps, and an example analysis of different budget scenarios for a pavement network is provided.

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PERFORM PCI SURVEY

The PCI is a score of 0 to 100, with 100 being excellent. It is determined on the basis of measured distress. A detailed description of the PCI is beyond the scope of this paper. The PCIs for roads (*1*) and airfields (*2*) have been described elsewhere. The PCI for airfields has been recently published as ASTM standard D5340-93, Standard Test Method for Airport Pavement Condition Index Surveys.

The pavement network is divided into uniform sections on the basis of use, pavement structure, construction history, traffic, and other factors. For the purpose of PCI inspection, pavement sections are divided into sample units. For asphalt pavements a sample unit is approximately 230 m^2 (2,500 ft^2) for roads and 460 m^2 (5,000 ft^2) for airfields. For concrete pavements a sample unit is approximately 20 slabs.

When performing PCI survey at the network level (versus the project level) very few sample units from each section need to be inspected. Analysis of budget scenarios is a network-level activity. The number of sample units to be inspected is a function of section size. The following table is an example inspection schedule used by one agency.

Section Size	*Survey*
1 to 5 sample units	1 sample unit
6 to 10 sample units	2 sample units
11 to 15 sample units	3 sample units
16 to 40 sample units	4 sample units
more than 40 sample units	10 percent

The sample units surveyed are selected to be representative of the average condition of the section.

DEVELOP PAVEMENT FAMILY DETERIORATION CURVES

The first step in developing the deterioration curves is to group the pavement into sections. The grouping is selected by the user on the basis of factors such as pavement type and use (Figure 1). For example, one family may include all secondary (collector) asphalt roads. When the data for a pavement family have been identified datum points are filtered to remove points in error.

The filtered data are then examined to identify datum points that are statistically outliers. The outlier procedure was developed on the basis of research findings (*3*) that the errors between the predicted and observed PCIs are normally distributed. A confidence interval is set by the user; data beyond this interval are identified as outliers.

Category	Example
• Branch Use	Roadway, Runway
• Pavement Rank	Primary, Secondary
• Surface Type	AC, PCC
• Zone	1200,1300
• Section Category	A, B
• Last Construction Date	> DEC / 30 / 1945

FIGURE 1 Pavement family definition.

Figure 2 is an example of outlier processed data with 95 percent confidence limits. The remaining datum points are then fitted with a fourth-degree polynomial by using the constrained least-squares procedure (Figure 3).

The PCI prediction at the section level is performed by assuming that the deterioration of all pavements in a family is similar and is a function of only their present condition, regardless of age. A section prediction curve is developed through the section's latest PCI/age point, parallel to its family curve (Figure 4).

IDENTIFY CRITICAL PCI FOR EACH FAMILY

A critical PCI is defined as the PCI value at which the rate of PCI loss increases with time or at the point when the cost of applying localized preventive maintenance increases significantly.

The critical PCI for a family is identified as follows:

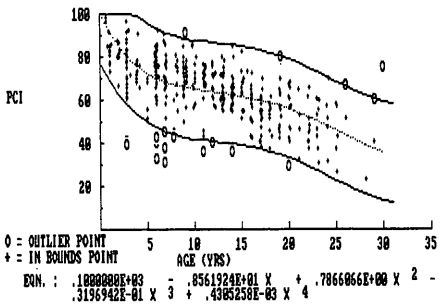


FIGURE 2 Outlier processed data file FNRSAC constrained to 4th-degree curve.

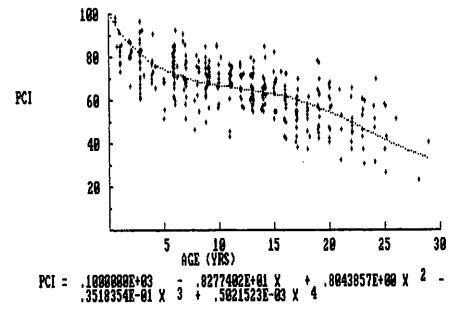


FIGURE 3 Constrained 4th-degree curve for data file.

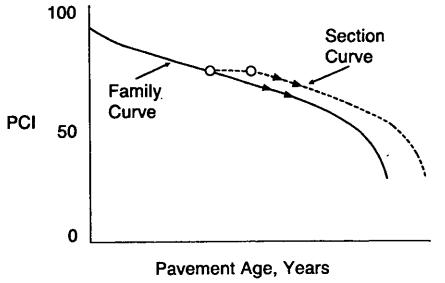


FIGURE 4 Section condition prediction.

1. Visually select the critical PCI range on the basis of the shape of the family deterioration curve (Figure 5).
2. Select a localized preventive distress maintenance policy to be used in the analysis of budget scenarios. Figure 6 is an example of such a policy for asphalt roads.
3. Apply the selected preventive distress maintenance policy to pavement sections in the family. This can be done by using the Micro PAVER network maintenance report.
4. Plot the cost of localized preventive maintenance per unit area versus PCI for each section. Figure 7 is an example of such a plot.
5. Select the critical PCI on the basis of the results from Steps 1 and 4.

ASSIGN M&R TO EACH PAVEMENT SECTION

There are seven M&R types in the current version of Micro PAVER: localized stopgap, localized preventive type, three global preventive types, and two major types. M&R types are assigned to each pavement section on the basis of the section's PCI with respect to the critical PCI (Figure 8). The following is a description of each of the M&R types.

Localized Stopgap (Safety)

Stopgap M&R is defined as the localized distress M&R activities needed to keep the pavement in a safe and operational condition. A stopgap policy is different from a preventive policy in that it will usually include only high-severity-level distresses that could be a safety hazard. Stopgap maintenance should only be applied to pavements with PCIs below the critical PCI.

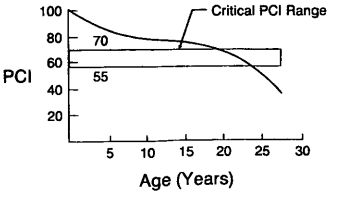


FIGURE 5 Critical PCI range on typical deterioration curve.

Policy Number: 2 Policy Description: PREVENTIVE , ROADS

Distress	Sev	Work Type & Description	Cost	Unit
1 ALLIGATOR CR	M	PA-AD Patching - AC Deep	5.00	sq. ft.
1 ALLIGATOR CR	H	PA-AD Patching - AC Deep	5.00	sq. ft.
3 BLOCK CR	M	CS-AC Crack Sealing - AC	.60	ft.
3 BLOCK CR	H	CS-AC Crack Sealing - AC	.60	ft.
4 BUMPS/SAGS	M	PA-AS Patching - AC Shallow	2.00	sq. ft.
4 BUMPS/SAGS	H	PA-AS Patching - AC Shallow	2.00	sq. ft.
5 CORRUGATION	M	PA-AL Patching - AC Leveling	1.00	sq. ft.
5 CORRUGATION	H	PA-AD Patching - AC Deep	5.00	sq. ft.
6 DEPRESSION	M	PA-AD Patching - AC Deep	5.00	sq. ft.
6 DEPRESSION	H	PA-AD Patching - AC Deep	5.00	sq. ft.
7 EDGE CR	M	CS-AC Crack Sealing - AC	.60	ft.
7 EDGE CR	H	PA-AD Patching - AC Deep	5.00	sq. ft.
8 JT REF. CR	M	CS-AC Crack Sealing - AC	.60	ft.
8 JT REF. CR	H	CS-AC Crack Sealing - AC	.60	ft.
9 LANE SH DROP	M	PA-AL Patching - AC Leveling	1.00	sq. ft.
9 LANE SH DROP	H	PA-AL Patching - AC Leveling	1.00	sq. ft.
10 L & T CR	M	CS-AC Crack Sealing - AC	.60	ft.
10 L & T CR	H	CS-AC Crack Sealing - AC	.60	ft.
11 PATCH/UT CUT	H	PA-AD Patching - AC Deep	5.00	sq. ft.
13 POTHOLE	L	PA-AD Patching - AC Deep	5.00	sq. ft.
13 POTHOLE	M	PA-AD Patching - AC Deep	5.00	sq. ft.
13 POTHOLE	H	PA-AD Patching - AC Deep	5.00	sq. ft.
15 RUTTING	M	PA-AD Patching - AC Deep	5.00	sq. ft.
15 RUTTING	H	PA-AD Patching - AC Deep	5.00	sq. ft.
16 SHOVING	M	PA-AS Patching - AC Shallow	2.00	sq. ft.
16 SHOVING	H	PA-AS Patching - AC Shallow	2.00	sq. ft.
17 SLIPPAGE CR	L	PA-AS Patching - AC Shallow	2.00	sq. ft.
17 SLIPPAGE CR	M	PA-AD Patching - AC Deep	5.00	sq. ft.
17 SLIPPAGE CR	H	PA-AD Patching - AC Deep	5.00	sq. ft.

FIGURE 6 Preventive distress maintenance policy for asphalt roads.

Localized Preventive

Localized preventive M&R is defined as localized distress maintenance activities that are performed with the primary objective of slowing the rate of condition deterioration. These activities include crack sealing and various patching techniques. An example of a localized preventive distress maintenance policy is shown in Figure 6. This policy is applied to pavements above the critical PCI. It should be noted that application of a localized preventive maintenance policy to pavement sections with PCIs below the critical PCI is not cost-effective.

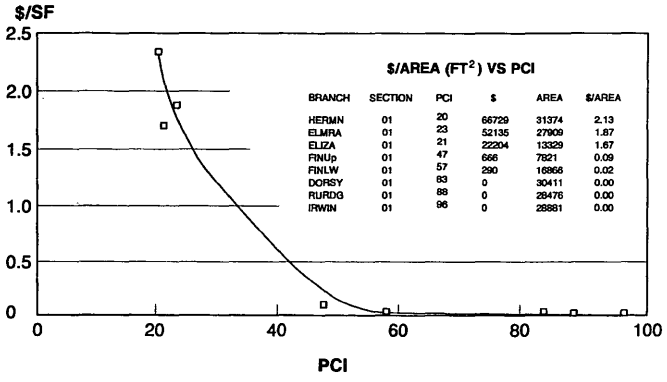


FIGURE 7 Localized preventive maintenance per unit area versus PCI for each section.

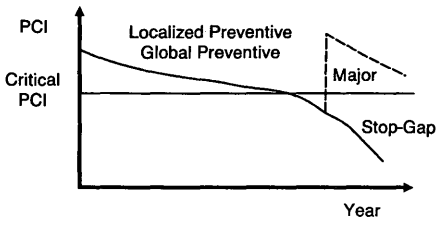


FIGURE 8 M&R types.

Global Preventive

Global preventive M&R is defined as those activities that are applied to the entire pavement section with the primary objective of slowing the rate of condition deterioration. These activities include surface treatments for asphalt-surfaced pavements and joint sealing for concrete pavements. Global preventive M&R is applied to pavements above the critical PCI. Applying global preventive M&R to pavements below the critical PCI is often not cost-effective.

The current version of Micro PAVER accommodates three types of global preventive M&R for asphalt-surfaced pavements. These three types are assigned to the pavement sections on the basis of existing distress types, as shown in Figure 9. This is done to optimize the selection of the surface treatment type on the basis of the existing distresses. Type 3 is recommended for pavements with skid causing distresses such as bleeding. Type 2 is recommended for pavements with climate-related distresses such as block cracking.

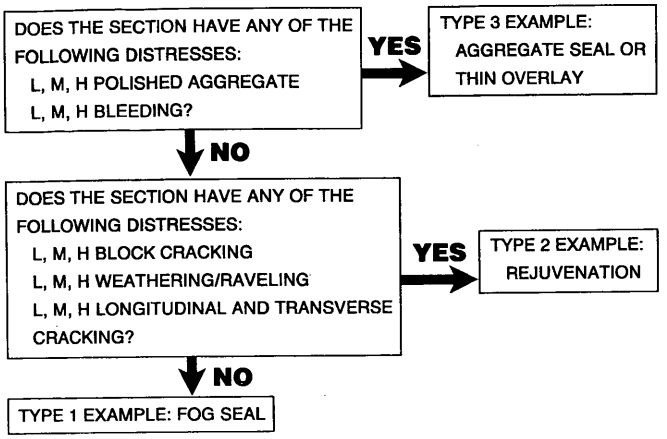


FIGURE 9 Process of assignment of one of three types to pavement sections.

The selection of the M&R type is also a function of the use of the pavement. For example, aggregate seals may not be appropriate for runways because of the possibility of foreign object damage to aircraft engines. Instead, a thin overlay should be used.

Major M&R

Major M&R is applied to the entire pavement section to correct or improve existing structural or functional requirements. Major M&R is divided into two types: major M&R applied to pavement sections above the critical PCI and major M&R applied to pavements below the critical PCI.

PRIORITY RANK M&R

Factors used to priority rank M&R include M&R type, pavement use, pavement rank, and PCI value. Priorities are first established on the basis of the M&R type as follows, with Priority 1 being the highest priority:

1. Localized stopgap (safety);
2. Localized preventive;
3. Global preventive, type 1;
4. Global preventive, type 2;
5. Global preventive, type 3;
6. Major, equal, or above the critical PCI; and
7. Major, below the critical PCI.

For M&R Types 1 through 5 priorities are assigned within each type on the basis of the section PCI, with the lower PCI receiving higher priority. For example, within M&R type 1 a pavement section with a PCI of 20 would receive a higher priority than a pavement section with a PCI of 50.

For M&R Types 6 and 7 priorities are assigned within each type on the basis of the user-defined criterion as shown in Figure 10. Pavement sections located within each major M&R type are ranked on basis of their PCIs, with the pavement with the lower PCI receiving a higher priority.

PCI \ Rank	Roadway P	S	T
70 - 100	2	4	10
Critical - 70	1	3	9
40 - Critical	1	3	9
0 - 40	2	4	10

FIGURE 10 Major M&R priority table.

CALCULATE M&R COST

The calculation procedure is slightly different for pavement sections above and below the critical PCI.

Pavement Sections Above Critical PCI

The first step is to investigate whether the pavement section has a structural distress (Figure 11). Structural distresses include alligator cracking and rutting in asphalt pavements and corner break and divided slabs in concrete pavements.

Pavement Sections with No Structural Distress

1. Apply localized preventive M&R by using the preventive distress maintenance policy and the extrapolated distress data from the last condition survey. For subsequent years in which the PCI is predicted but the distress information is not available, the cost of localized preventive maintenance is estimated on the basis of the user-specified PCI versus unit cost relationship (Figure 12).
2. Apply global preventive M&R on the basis of the user-specified interval between applications. Also the maximum number of applications per pavement section should not be exceeded. The selection of the type of global M&R for asphalt pavements was presented in Figure 9.
3. If a global M&R is selected then the section's PCI will be increased as per specified value (Figure 13). A preferred method for

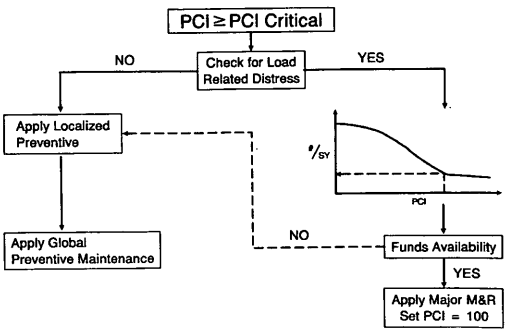


FIGURE 11 Investigation of pavement sections with PCIs above critical PCI.

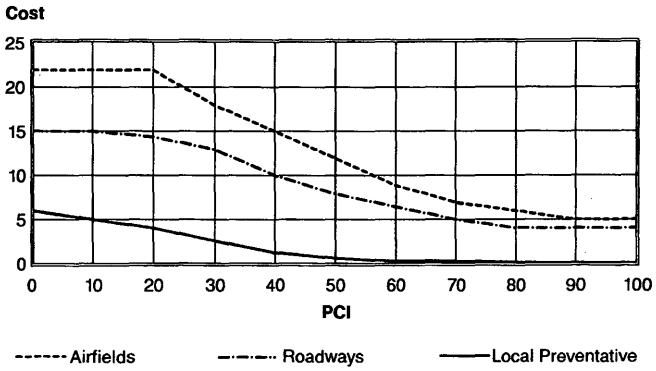


FIGURE 12 M&R cost/yd².

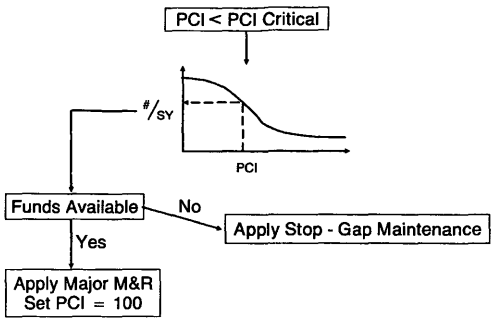


FIGURE 14 Investigation of pavement sections with PCIs less than critical PCI.

accounting for the effect of global preventive maintenance on pavement performance is to let the user specify the ultimate increase in pavement life (ΔT) and calculate the effective increase in PCI (ΔPCI) (Figure 13).

Pavement Sections with Structural Distress

1. Determine the cost for major M&R on the basis of the PCI versus unit cost relationship (Figure 12).
2. Check the availability of funds on the basis of the available budget and major M&R priorities.
3. If funds are available apply major M&R and set the PCI value to 100. If funds are not available apply the same process as described for pavement sections with PCIs above the critical PCI. Check on the availability of funding for major M&R in the following years.

Pavement Sections Below Critical PCI

1. Determine the cost for major M&R on the basis of the user-specified PCI versus unit cost relationship (Figures 12 and 14).
2. Check on the availability of funds on the basis of the budget and priorities.
3. If funds are available apply major M&R and set the PCI value to 100. If funds are not available apply localized stopgap (safety) M&R. Check on the availability of funding for major M&R in the following years.

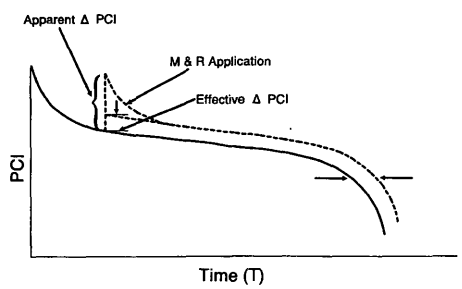


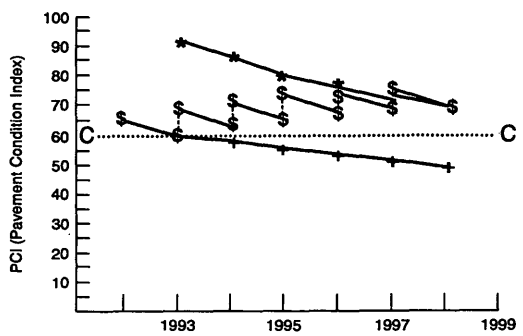
FIGURE 13 Determination of increase in PCI (ΔPCI) because of increase in life (ΔT).

EXAMPLE BUDGET SCENARIO ANALYSIS

The budget scenario analysis procedure presented previously has been automated as part of the Micro PAVER system. The following example is for a road network that is approximately 1.3 million m² (1.5 million yd²). The network is divided into more than 200 pavement sections. The average PCI for the network was 66 in 1992.

Three budget scenarios were analyzed for the planning period 1993 to 1999 on the basis of an unlimited annual budget, an annual budget of $100,000/year (stopgap budget), and an annual budget of $2.0 million/year (affordable budget).

Figure 15 shows a comparison of the average network PCI for each of the three budget scenarios. The analysis showed that the $100,000/year (stopgap budget) will result in a cumulative backlog of M&R (unfunded requirements) of $14.6 million in 1999. The unlimited budget resulted in the lowest total cost of $10.6 million, as compared with $15.3 million for the budget of $100,000/year. The unlimited budget, however, required $6 million to be spent in the first year (1993), which was not obtainable. A $2 million annual budget was approved, which resulted in a total cost of $12.5 million.



	Budget Limit	M&R cost	Unfunded @ 1999	Total Cost
*	Unlimited	10.6M	0	10.6M
$	2M/YR	12.3M	0.2M	12.5M
+	100K/YR	0.7M	14.6M	15.3M

FIGURE 15 Network PCI-budget comparison.

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The views of the author do not purport to reflect the position of the U.S. Department of the Army or the U.S. Department of Defense.