# Evaluation of Airfield Pavement Condition and Determination of Rehabilitation Needs

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This paper presents a comprehensive procedure for the evaluation of the condition of an airfield pavement and the determination of its maintenance and rehabilitation needs. The overall procedure consists of three steps: The first is the determination of the airfield-pavement-condition rating based on a pavement-condition index. This index is a score between 0 and 100 that describes the structural integrity of the pavement and its surface operational condition and is based on measured types, severities, and amounts of distress. The index, and hence the pavement-condition rating (i.e., excellent, very good, good, fair, poor, very poor, or failed), agrees closely with the collective judgment of experienced pavement engineers and is strongly correlated to the need of the pavement for maintenance and rehabilitation. The second step is the evaluation of the pavement through a stepwise procedure. The purpose of the evaluation is to provide the necessary background for a rational determination of feasible maintenance and rehabilitation alternatives. The stepwise evaluation procedure depends largely on the pavement-condition-index and distress data but other direct measurements, such as profile roughness, hydroplaning potential, and load-carrying capacity, are also included. The third step is the determination of the optimum maintenance and rehabilitation alternative. Feasible alternatives are determined through the use of guidelines that are based on the results of the stepwise evaluation and include recommended methods for the localized repair of different types of distress at different levels of severity. After the feasible alternatives are identified, an economic analysis is performed. The optimum alternative is selected based on the results of the economic analysis, the mission of the pavement, and the policies of the airfield management. The procedure is illustrated by an example.

The first step in determining the maintenance and rehabilitation (M&R) needs of and alternatives for a given pavement feature is an accurate and comprehensive evaluation of its existing condition.

The condition of an airfield pavement can be evaluated in terms of factors called condition indicators; comprehensive pavement-condition evaluation requires the measurement of these condition indicators, which include at least the following:

1. Operational surface indicators: (a) roughness (both localized and profile roughness), (b) skid resistance and hydroplaning potential, and (c) potential for foreign object damage (FOD) (to jet engines);
2. Structural indicators: (a) structural integrity (cracking, distortion, and disintegration) and (b) load-carrying capacity; and
3. Other indicators: (a) rate of deterioration and (b) amount of previous M&R applied.

Many of these condition indicators are interrelated; for example, surface distortion and disintegration are related to surface roughness. A complete condition evaluation requires the consideration of each condition indicator individually and of all the indicators collectively.

Most of these pavement condition indicators are related to observable pavement distress, as shown in Figure 1 (for asphalt-surfaced pavement); there is a similar correlation for rigid pavements (1). In most cases, the observable pavement distress gives a good indication of pavement condition: FOD potential, structural integrity, roughness (short wave lengths only), and rate of deterioration can be determined in this manner.

In this paper, the development is described of a composite index that relates airfield pavement cracking, distortion, and disintegration. The index, which is known as the pavement-condition index (PCI) has been officially adopted and is being used extensively by the U.S. Air Force. The PCI is a score between 0 and 100 that agrees closely with the average rating (collective judgment) of experienced pavement engineers and is strongly related to the need for M&R.

The stepwise evaluation procedure presented in this paper is based on the use of the PCI, distress data, rate of deterioration, and other direct measurements (such as skid potential and profile roughness). The PCI and distress data were selected as the basis for the evaluation because they showed strong correlations with M&R needs. Guidelines for identifying feasible M&R alternatives based on the results of the evaluation are presented. The selection of the optimum M&R alternative should be based on economics, pavement mission, and management policies.

The application of these procedures is illustrated for a plain-jointed concrete runway in Illinois.

## PAVEMENT-CONDITION INDEX

### Description

The PCI is a numerical indicator of pavement condition that is directly related to the structural integrity of the pavement (its ability to resist fracture, distortion, and disintegration) and its surface operational condition. The PCI is a function of (a) type of distress ($T_i$); (b) severity of distress ($S_j$), such as width and degree of spalling of cracks or depth of ruts; and (c) density of distress ($D_{ij}$), which is the percentage of the area of the pavement that is distressed. The development of a meaningful condition index requires the inclusion of all three of these distress characteristics. The PCI is expressed mathematically as follows:

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

where

- $C$ = constant that depends on desired maximum scale value;
- $a(\ )$ = deduct weighting value that depends on $T_i$, $S_j$, and $D_{ij}$;
- $i$ = counter for types of distress;
- $j$ = counter for levels of severity;
- $p$ = total number of types of distress for pavement type under consideration;
- $m_i$ = number of severity levels on the $i$th type of distress; and
- $F(t, q)$ = adjustment function for multiple distresses that

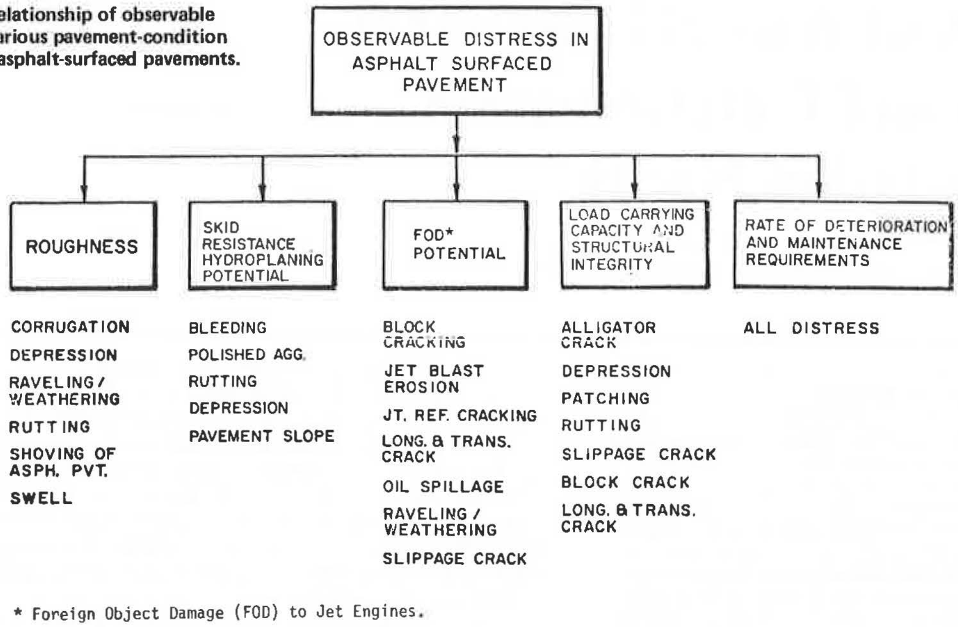



**Figure 1. Relationship of observable distress to various pavement-condition indicators: asphalt-surfaced pavements.**

varies with total summed deduct value (t) and number of deducts (q).

The development of the PCI consisted of defining the types of distress and the levels of its severity (2) and of developing the individual distress deduct curves and an adjustment function for multiple-distress correction (3).

## Determination of Pavement-Condition Index of a Pavement Feature

A pavement feature is defined as a portion of pavement that (a) has consistent structural thickness and materials, (b) was constructed at one time, and (c) is subjected to the same type and approximately the same number of traffic repetitions.

The PCI of a given pavement feature is determined by carrying out the following steps (see Figure 2):

1. The pavement feature is first divided into sample units. A sample unit for concrete pavement is approximately 20 slabs; a sample unit for asphalt is an area of approximately 465 $m^2$ (5000 $ft^2$).
2. The sample units are inspected and the types of distress and their severity levels and densities are recorded. The criteria given by Shahin and others (4) should be used in identifying and recording the types of distress.
3. For each type, density, and severity level of distress within a sample unit, a deduct value is determined from an appropriate curve (4) (see step 3 in Figure 2 for an example of such a curve).
4. The total deduct value (TDV) is determined by adding all of the deduct values for each distress condition observed for each sample unit inspected.
5. A corrected deduct value (CDV) is determined from the appropriate curve (4); the CDV is based on the TDV and the number of distress conditions observed that have individual deduct values higher than five points (see step 5 in Figure 2).
6. The PCI for each sample unit inspected is calculated as follows:

$$PCI = 100 - CDV \quad (2)$$

7. The PCI of the entire feature is computed by averaging the PCIs of all the sample units inspected.
8. The pavement condition rating of the feature is determined by using step 8 of Figure 2, which presents verbal descriptions of pavement condition as a function of PCI value.

An inspection by sampling procedure has been developed to expedite inspection without loss of accuracy and has been widely accepted and used by the Air Force engineers. A computer program has also been developed to expedite the PCI calculations (4).

## EVALUATION OF PAVEMENT FEATURE FOR SELECTION OF MAINTENANCE AND REHABILITATION ALTERNATIVES

In this section, the steps are presented for the evaluation of the condition of a pavement feature. The major emphasis is on the use of the PCI and distress data for the determination of condition because these items have been found to be strongly correlated with maintenance and repair needs, but the use of other direct measurements to supplement and verify evaluations in critical situations is also described.

Figure 3 is a summary of the steps in the pavement-condition evaluation. Following is a brief description of each:

1. Overall condition: The mean PCI of a pavement feature is an estimation of the overall condition of the pavement and represents the consensus of opinion of a group of experienced pavement engineers.
2. Variation of PCI within feature: Because of variations of materials, construction, subgrade, and traffic loadings, certain portions of a given pavement feature may show a significantly different condition than the average for the overall feature. Areas that have a poorer condition are of major concern. Variation within a feature occurs on both a localized random basis (i.e., from material and variability) and a systematic basis (i.e., from traffic patterns).

Figure 4 has been developed from field data to provide guidelines for determining whether localized random variation exists. For example, if the mean PCI of a

Figure 2. Steps in determining pavement-condition indicator of a pavement feature.

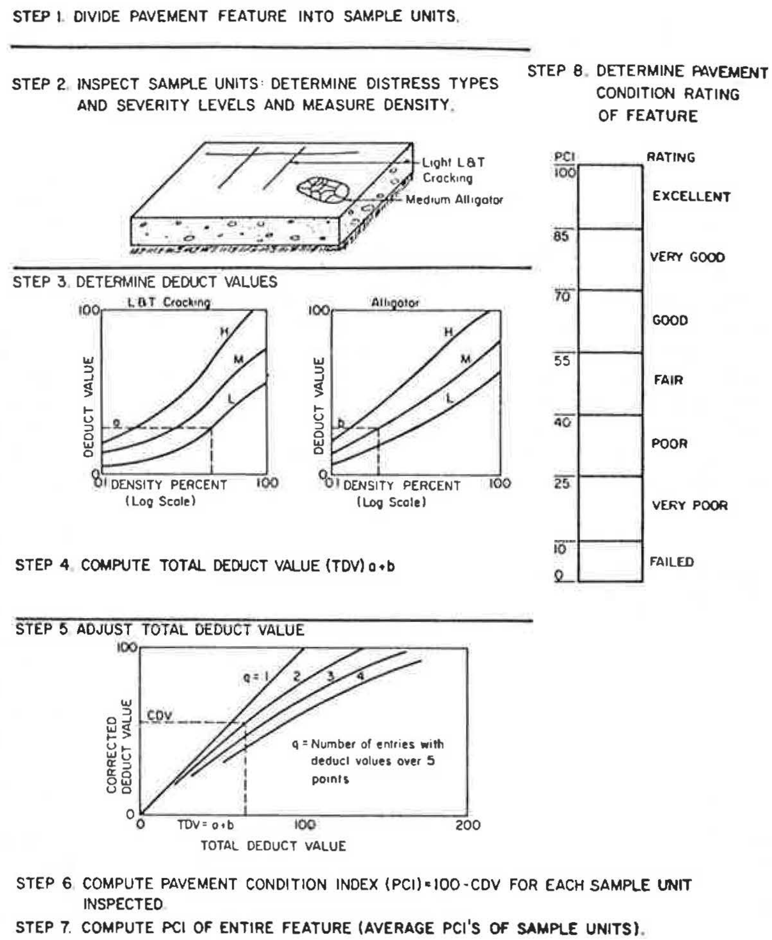



Figure 3. Form for evaluation of airfield pavement condition.

1. Overall Condition Rating - PCI
   Excellent, Very Good, (Good,) Fair, Poor, Very Poor, Failed.
2. Variation of Condition Within Feature - PCI
   a. Localized Random Variation — (Yes,) No
   b. Systematic Variation — (Yes,) No
3. Rate of Deterioration of Condition - PCI
   a. Long-term period (since construction) — (Low,) Normal, High
   b. Short-term period (1 year) — Low, Normal, (High)
4. Distress Evaluation
   a. Cause
      (Load Associated Distress — 58) percent deduct values
      Climate/Durability Associated — 36 percent deduct values
      Other (Fault) Associated Distress — 6 percent deduct values
   b. Moisture Accelerated Distress — Minor, (Moderate,) Major
5. Load Carrying Capacity Deficiency — No, (Yes)
6. Surface Roughness — Minor, (Moderate,) Major
7. Skid Resistance/Hydroplaning (runways only)
   a. Mu-Meter — No hydroplaning problems are expected / Transitional / Potential for hydroplaning / Very high probability
   b. Stopping Distance Ratio — No hydroplaning anticipated / Potential not well defined / Potential for hydroplaning / Very high hydroplaning potential
   c. Transverse Slope — Poor, Fair, (Good, Excellent)
8. Previous Maintenance — Low, Normal, (High)

Note: Circled items relate to field-case study described in this paper.

feature is 59, any sample unit having a PCI of less than 42 should be identified as a localized bad area. This variation or localized bad area should be considered in determining M&R needs.

Systematic variation occurs whenever a large concentrated area of the feature has a condition that is significantly different from the rest. For example, on a wide runway or a large apron where traffic is channeled to a certain portion, that portion may show much more distress (or poorer condition) than the rest of the area. Whenever there is a significant degree of systematic variability within a feature, strong consideration should be given to dividing the feature into two or more features.

3. Rate of deterioration: For jointed concrete-surfaced pavements, the relative rate of long-term deterioration from initial construction can be determined from Figure 5, which was obtained by plotting all available data on the features surveyed [a similar figure was also developed for asphalt-surfaced pavements (1)]. In

Figure 4. Procedure for determination of minimum sample unit PCI based on mean PCI of feature.

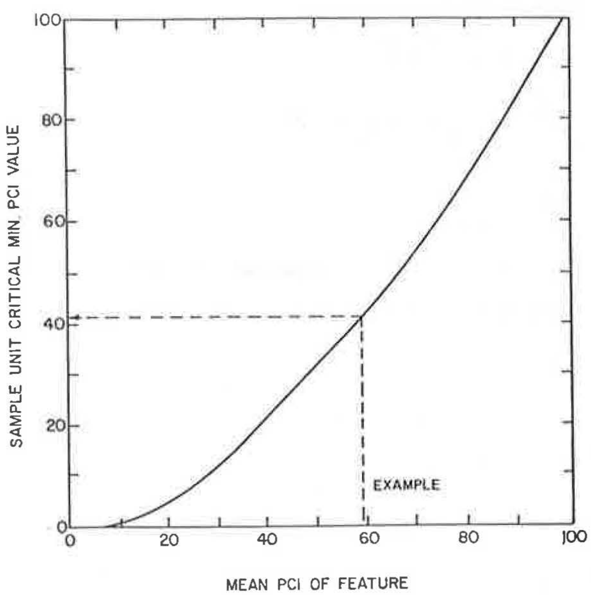



Figure 5 (and the similar one for asphalt-surfaced pavements), each point represents one pavement feature, the solid central line represents the overall average rate of deterioration of the pavement features, and the dashed lines are intended to envelop a majority of the data to represent normal rates of deterioration. These data points represent a great variety of pavement designs, traffic, climates, soils, and other factors, and thus the overall average expected loss of condition. A pavement feature that is above the upper dashed line is considered to have a low rate of deterioration, and a feature that is below the lower dashed line is considered to have a high rate of deterioration. Thus, a concrete pavement feature that has a PCI of 40 after 20 years is considered to have a high long-term rate of deterioration, but one that has a PCI of 60 is considered to have a normal long-term rate of deterioration.

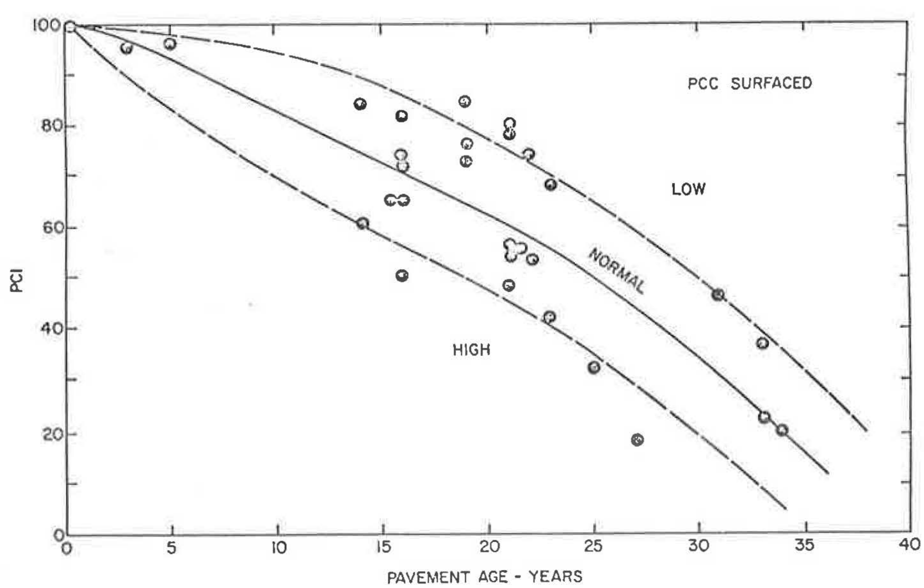
The rate of deterioration of a pavement can also be evaluated in terms of the short-term or annual decrease in the PCI. A decrease in the mean PCI of a feature (assuming only normal routine M&R has been applied) of seven or more PCI points indicates a high short-term rate of deterioration; a decrease of four to six points indicates a normal or average short-term rate of deterioration.

4. Pavement distress: The PCI is a composite index of existing airfield-pavement distress. However, examination of the specific types, severities, quantities, and causes of individual distresses also provides a valuable aid in determining condition and eventually selecting M&R needs. Distress occurs as a result of traffic loads, climatic conditions, material durability, and other factors. The types of distress have been divided into three main groups: (a) those caused primarily by traffic loadings, (b) those caused primarily by material durability and climate, and (c) those caused by other factors. Conditions at each pavement will dictate the specific distresses that belong in each group.

The following steps constitute a procedure for determining the primary cause or causes of the deterioration of the pavement condition of a given feature:

First, the total deduct values attributable to load, climate and durability, and other distresses are separately determined. For example, the following distresses were measured on an asphalt feature and the deduct values were determined:

Figure 5. Relationship between PCI of pavement feature and time since construction: concrete-surfaced pavement.



| Type of Distress | Deduct Value | Cause |
|---|---|---|
| Alligator cracking | 50 | Load |
| Transverse cracking | 8 | Climate and durability |
| Rutting | 20 | Load |

Thus, the total deduct value attributable to load is 70 and that attributable to climate and durability is 8.

Second, the percentage deduct values attributable to load, climate and durability, and other causes are computed. For the above example feature, the calculation is as follows:

Load = $(70/78) \times 100 = 90$ percent
Climate and durability = $(8/78) \times 100 = 10$ percent
Total = 100 percent.

Third, the percentage deduct values attributed to each cause form the basis for the determination of the primary cause(s) of pavement deterioration. In this example, distresses caused primarily by load have caused 90 percent of the total deduct value, whereas all other causes amount to only 10 percent. Thus, traffic load is by far the major cause of deterioration of this pavement feature.

5. Evaluation of load-carrying capacity: The load-carrying capacity of an airfield pavement is defined in terms of three factors: (a) the aircraft gross weight, (b) the type of aircraft, and (c) the number of aircraft passes over the pavement until a "failed" condition is predicted. If these three factors are held constant, the load-carrying capacity depends on the pavement structure and material properties and the subgrade soil properties. For years, the U.S. Air Force has determined the load-carrying capacity of airfield pavements by using procedures developed by the U.S. Army Corps of Engineers (5). Research efforts are under way to develop nondestructive testing methods and criteria for evaluating the load-carrying capacity of airfield pavements. The results of this development could be used to replace the older procedure.

6. Surface roughness: There are currently three methods for estimating surface roughness. First, pilot complaints are subjective but highly reliable sources of qualitative roughness information. The pilot reports reflect aircraft ride quality as well as surface roughness; the additional factor of aircraft vibration is therefore included.

Second, certain types of distress contained in the PCI can be correlated with localized roughness as shown in Figure 1. However, it is difficult or impossible to see the longer wave-length roughness that affects aircraft ride quality when inspecting a runway surface.

Third, the roughness can be quantitatively evaluated, on a relative basis, by analyzing measured profile-elevation data. [The development of this approach formed a large part of a joint Federal Aviation Administration and U.S. Air Force research program and is discussed in more detail elsewhere (6).] This method has required the development of rapid elevation-measuring instruments and suitable data-processing techniques involving filtering and statistical analysis of random data as well as the use of computer programming for the estimation of aircraft vibration response.

7. Skid resistance and hydroplaning potential: The Air Force (7) reports pavement skid resistance in terms of the coefficient of friction as measured by a Mu-Meter (8) and the wet-to-dry stopping distance ratio as measured by the diagonally braked vehicle (9). Transverse slope can also be measured by survey techniques.

8. Previous M&R applied: A pavement feature can be kept in operating condition almost indefinitely if extensive M&R is continually applied. There are major disadvantages to this maintenance strategy, however, such as overall cost, downtime of the feature, the increase in roughness caused by excessive patching, limitations of personnel and equipment, and airfield mission requirements. The amount and types of previous M&R applied to a pavement feature are important factors in determining currently needed M&R. A pavement where a large portion has been patched or replaced must have had many previous distress problems that are likely to continue in the future.

Permanent patching and slab replacement may be used as a criterion for evaluating previous maintenance. Patching and slab replacement of 1.5-3.5 percent is considered normal, more than 3.5 percent is considered high, and less than 1.5 percent is considered low. Some pavement features may also have received an excessive amount of M&R other than patching. If, in the judgment of the engineer, this should be evaluated as high previous maintenance, then this evaluation should take precedence over the evaluation based only on patching and slab replacement.

## MAINTENANCE AND REHABILITATION NEEDS

The selection of the optimum M&R category (i.e., routine, major, or overall) for a given pavement feature is a major decision that requires many years of experience in pavement maintenance and repair. In many cases, a group of experienced pavement engineers will agree on a recommended M&R category. In many other cases, however, disagreement will occur and a thorough examination of the pavement condition evaluation and a comprehensive economic analysis will be required for the selection of the correct M&R category and the optimum M&R alternative.

### Maintenance and Rehabilitation Categories

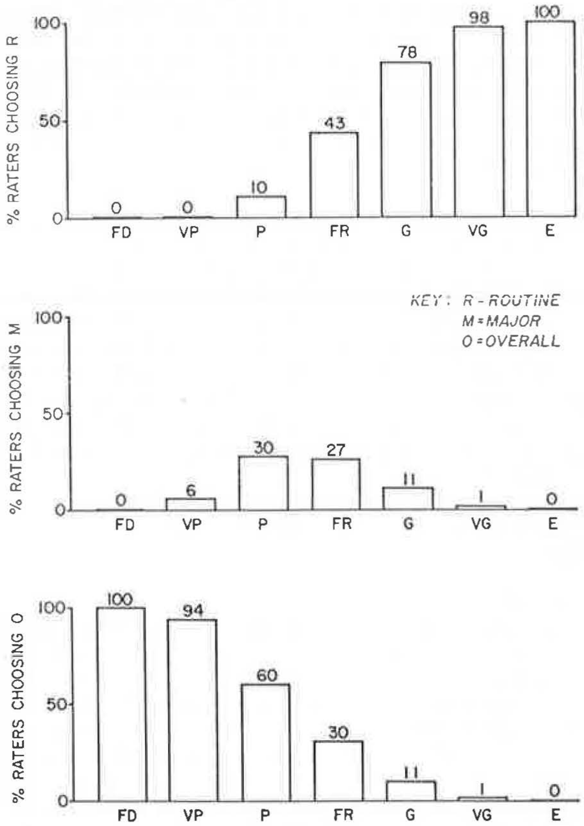
M&R methods (such as crack filling, patching, slab replacement, and overlay) are grouped into three general categories for convenience of analysis and discussion.

1. Routine M&R: Routine M&R consists of performing preventive or localized M&R. Preventive M&R includes methods that preserve the condition of the pavement and retard its deterioration. These methods include crack sealing, joint sealing, and application of fog seals and rejuvenators. Application of aggregate seals, however, is considered to be major localized M&R. Localized M&R methods are those that restore pavement condition. Some repair methods are considered localized if they are applied to only a small area of the pavement feature; for example, skin patching, applying heat and rolling sand, placing small patches [$0.46\ m^2$ ($5\ ft^2$)], and patching joint and corner spalls are considered localized regardless of amount. On the other hand, partial-depth or full-depth patching, slab replacement, slab undersealing, slab jacking, and slab grinding are considered localized only if applied to a small area of the pavement feature (usually less than 3.5 percent).

2. Major localized M&R: Major localized M&R is an extensive form of localized M&R. It includes partial-depth or full-depth patching, slab replacement, slab undersealing, and slab grinding when applied to a considerable area or portion of the pavement feature (usually more than 3.5 percent). Other M&R methods included in the major localized category are the application of an aggregate seal over the entire feature and the reconstruction of many joints in a concrete pavement.

3. Overall M&R: Overall M&R includes procedures that cover the entire pavement feature and usually im-

Figure 6. Relationship between percentage of engineers recommending M&R category and PCI.




proves its load-carrying capacity. Overall M&R includes overlays with asphalt or concrete, reprocessing or recycling of existing pavements, and total reconstruction.

## Maintenance and Rehabilitation Guidelines

Excellent correlation was found between the PCI and the M&R categories. The correlation was based on results obtained from 37 airfield pavement features that included runways, taxiways, and aprons and represent a wide variety of climates, traffic, ages, and structures. Eighteen of the features were asphalt- or tar-surfaced pavements, and 19 were jointed concrete. During the field surveys of the features, all existing distress was measured, 35-mm color slides were taken, the pavement structure and age were determined, and the primary aircraft were identified. This information was given to 10 experienced engineers to aid them in making M&R decisions (the PCIs for the features were not available to the engineers when recommending M&R requirements).

Figure 6 shows the percentage of engineers recommending routine, major, or overall M&R within the next two years of the life of the pavement for each condition-rating zone. These results show that the higher the PCI, the greater the percentage of engineers recommending only routine M&R and the lower the PCI, the greater the percentage recommending overall M&R. In the middle of the PCI scale (40 to 70), there is a lack of consensus as to which to recommend.

From these results, four M&R zones were established to provide guidelines for the selection of M&R. The four zones conveniently fit the condition-rating zones used with the PCI, as shown in the table below.

| M&R Zone | PCI | Rating |
|---|---|---|
| Routine | 100 | Excellent |
| | 85 | Very good |
| Routine, major, overall | 70 | Good |
| | 55 | Fair |
| Major, overall | 40 | Poor |
| Overall | 25 | Very poor |
| | 10-0 | Failed |

1. Routine M&R zone (R-zone). In this zone, nearly all engineers recommended only routine M&R for the next two years. The specific routine M&R methods are determined based on types and severities of distress, as shown in Tables 1 and 2. Major or overall M&R would be recommended only in exceptional cases such as those where the pavement-condition evaluation (Figure 3) indicates that one or more of the following items exists: (a) load-associated distress accounts for a major portion of the distress deduct value, (b) load-carrying capacity is deficient as indicated by a "Yes" rating, (c) rate of pavement deterioration is rated high, (d) previous M&R applied is rated high, (e) surface roughness is rated major, (f) skid resistance and hydroplaning potential is rated very high, and (g) a change in mission requires greater load-carrying capacity. Thus, the pavement engineer should concentrate on applying routine M&R to pavement features within this zone. Timely and effective routine M&R will reduce the rate of deterioration of the pavement.

2. Routine-major-overall zone (R-M-O zone): This zone includes all pavement features that have PCIs between 41 and 70 or a condition rating of fair or good. As shown in Figure 6, there is no general agreement among engineers as to which type of M&R should be applied. Generally, however, the higher the PCI in this zone, the higher the percentage of engineers recommending routine M&R. It is therefore recommended that either routine or major M&R generally be applied to pavement features in this zone (particularly those that are rated good). The specific routine or major M&R alternative that should be selected depends on the types and severities of distress as presented in Tables 1 and 2. Overall M&R should be considered only if the condition evaluation indicates that one or more of items a through g listed above exist.

3. Major-overall zone (M-O zone): This zone includes all pavement features having PCIs between 26 and 40 or a condition rating of poor. As shown in Figure 6, there is a consensus of opinion that pavement features in this condition should receive either major or overall M&R within the next two years. For example, for one feature that had a PCI of 35, overall M&R was recommended by 80 percent of the engineers and major M&R was recommended by 20 percent (none recommended routine). Some engineers apparently feel that a pavement in this condition needs significant M&R to prevent it from exceeding the point of economic repair, but many others feel that it has already exceeded that point. The decision to select major or overall M&R should be based primarily on an economic analysis of the alternatives. However, if the condition evaluation indicates that one or more of items a through g exist, overall M&R should be strongly considered.

4. Overall zone (O-zone): This zone includes all pavement features that have PCIs between 0 and 25 or a condition rating of very poor or failed. As shown in Figure 6, there is a consensus of opinion that pavement features in this condition should receive overall M&R within the next two years. The experienced engineers apparently feel that a pavement feature in this condition is beyond the point of economical repair and that only overall M&R will provide adequate results. The decision as

**Table 1. Recommended preventive and localized M&R: jointed concrete-surfaced airfield pavements.**

| Type of Distress | Doing Nothing | Crack Sealing | Joint Sealing | Partial-Depth Patching (bonded) | Full-Depth Patching | Slab Replacement | Slab Undersealing | Slab Grinding | Slab Jacking Grouting |
|---|---|---|---|---|---|---|---|---|---|
| Blowup | | | | L or M[a] | H[a] | H[a] | | | |
| Cornerbreak | L | L, M, or H | | | M or H | | | | |
| Longitudinal, transverse, or diagonal cracking | L | L, M, or H | | H[b] | H | H | | | |
| D-cracking | L | L[c] | L[c] | M or H | M or H | H | | | |
| Joint-seal damage | L | | M or H[d] | | | | | | |
| Small patches (<0.46 m²) | L | M | | M or H[e] | H[e] | | | | |
| Large patches (>0.46 m²) | L | M | | M or H[e] | H[e] | H | | | |
| Pop-outs | A | | | | | | | | |
| Pumping | | A | A | | | | A | | |
| Crazing and sealing | L | | | M or H | | H | | | |
| Settlement and faulting | L | | | | | H | | M or H | M or H |
| Divided slab | | L, M, or H | | | | M or H | | | |
| Shrinkage cracking | A | | | | | | | | |
| Joint spalling | L | | L or M | L, M, or H | M or H[g] | M or H[f] | | | |
| Corner spalling | L | | L or M | M or H | | | | | |

Notes: 1 m² = 10.8 ft².
A = type of distress that has only one severity level; L = low-severity distress; M = medium-severity distress; and H = high-severity distress.
[a]Must provide expansion joint.
[b]Allow crack to continue through patch except when using asphalt concrete.
[c]Seal all joints and cracks.
[d]Joint seal local areas.
[e]Replace patch.
[f]Only when surface is unacceptable.
[g]If caused by keyway failure, provide load transfer.

**Table 2. Recommended preventive and localized M&R: asphalt- or tar-surfaced airfield pavements.**

| Type of Distress | Doing Nothing | Crack Sealing | Partial-Depth Patching | Full-Depth Patching | Skin Patching | Heating and Sand Rolling | Fog Sealing[a] (emulsion) | Application of Rejuvenator | Application of Aggregate Sealing Coat |
|---|---|---|---|---|---|---|---|---|---|
| Alligator cracking | | | M or H | M or H | | | | L or M | |
| Bleeding | A | | | | | A | | | |
| Block cracking | L | L, M, or H | | | | | | L | L or M |
| Corrugation | L | M or H | M or H | | | | | | |
| Depression | L | M or H | M or H | M or H | | | | | |
| Jet blast | A | | A | | A | | A | | A |
| Joint reflection cracking | L | L, M, or H | H | | | | | | |
| Longitudinal and transverse cracking | L | L, M, or H | H | | | | | L | L or M |
| Oil spillage | A | | A | A | | | | | |
| Patching | L | M | M[b] | H[b] | | | | | |
| Polished aggregates | A | | | | | | | | A |
| Raveling and weathering | L | H | | | | | L or M | L | M or H |
| Rutting | L | | M or H | M or H | M or H | | | | |
| Shoving | L | M or H | | | | | | | |
| Slippage cracking | A | | A | | | | | | |
| Swelling | L | | | M or H | | | | | |

Note: A = type of distress that has only one severity level; L = low-severity distress; M = medium-severity distress; and H = high-severity distress.
[a]Requires prior approval by command pavement engineer.
[b]Replace patch.

to which overall M&R alternative to select should be based on an economic analysis of the feasible alternatives.

## Economic Analysis of Maintenance and Rehabilitation Alternatives

Based on the results of pavement-condition evaluation and the guidelines for M&R selection, the engineer may need to consider more than one M&R alternative for restoring the structural integrity and operational condition of the pavement. The selection of the best alternative often requires performing an economic analysis that compares the costs of all feasible alternatives. This section presents an economic analysis procedure that compares M&R alternatives based on total present worth.

1. Select an economic analysis period (in years). The period generally used in pavement analysis is in the range of 5-30 years, depending on the future use of the feature (e.g., abandonment or change of mission). When

the present-worth method of economic analysis is used, the alternatives must be compared over the same number of years. Thus, all alternatives must have equal life.

2. Select the interest rate ($r_t$) and the inflation rate ($r_f$) to be used for calculating the present cost.

3. Estimate the annual M&R cost for each M&R alternative for every year for which work is planned during the analysis period. The cost estimates should be based on current prices.

4. Determine the salvage value of the M&R alternatives. These are the values or worths of the pavement at the end of the analysis period and can be determined by subtracting the cost of rehabilitating or reconstructing the existing pavement structure from the cost of constructing a new pavement structure over the subgrade (assuming that no pavement exists). This difference in costs, then, is the value of the existing pavement (which may be a negative value if the pavement is badly deteriorated).

5. Calculate the total present worth for each M&R alternative as follows:

$$\text{Total present worth} = \left[\sum_{i=0}^{n} C_i \times f_i\right] - (S_v \times f_n) \qquad (3)$$

where

$n$ = number of years in analysis period,
$C_i$ = M&R cost for year i based on current costs,
$S_v$ = salvage value based on current costs,
$f_i$ = present-worth factor for ith year that is a function of $r_t$ and $r_f$; i.e., $f_i = [(1 + r_f)/(1 + r_t)]^i$.

After completion of these basic steps, comparison of the present worth for all M&R alternatives will assist the pavement engineer in selecting the most economic M&R alternative.

It should be emphasized that many predictions and assumptions must be made to perform the analysis. The engineer must therefore exercise judgment in selecting the best inputs and use the results of the analysis as an aid in decision making.

## APPLICATION OF MAINTENANCE AND REHABILITATION GUIDELINES AND ECONOMIC ANALYSIS: EXAMPLE

This section describes an example of the procedure for determining the optimum M&R alternative for a pavement feature. The steps included are data collection, condition evaluation, selection of feasible M&R alternatives, economic analysis, and selection of the optimum M&R alternative.

The pavement used in this example is a portion of a runway constructed in 1947 of plain jointed concrete. The pavement is 46 m (150 ft) wide and 841 m (2760 ft) long. The individual slab size is 3.8×6.1 m (12.5×20 ft). Figure 7 shows the slab layout for the runway.

The critical aircraft using the runway for the past eight years has been the DC-9 (before that time only light-load aircraft operated on the runway). The pavement is exhibiting distress that began after the DC-9 started operation on the runway. The pavement engineer is concerned about the current pavement deterioration and the amount of maintenance required.

A pavement-condition survey was performed on the feature in 1977. Before the actual survey, it was observed that most of the distress occurred within the central 15 m (50 ft) (i.e., in slab rows 5, 6, 7, and 8) and that all but a few of the tire rubber marks were contained within the central 22.7 m (75 ft) (slab rows 4, 5, 6, 7, 8, and 9). The condition of rows 1 to 3 and 10 to 12 was very similar, in that they exhibited only minor distress. Therefore, the six center rows of slabs were grouped as the pavement feature to be surveyed and analyzed.

All 828 slabs in the central six slab rows of the feature were surveyed by inspecting 46 sample units of 18 slabs each (6 slabs wide by 3 slabs long). The entire feature was surveyed, because it was desired to have extensive information for this example. A few random samples from the outer three rows of slabs on both sides of the runway were also surveyed. A plot of the PCI along the runway is shown in Figure 8. A summary of the types of distress found in the central six slab rows and the calculated percentage deduct values due to load and climate are shown in Table 3. (The overall evaluation summary of this pavement is shown in Figure 3.)

### Selection of Feasible Maintenance and Rehabilitation Alternatives

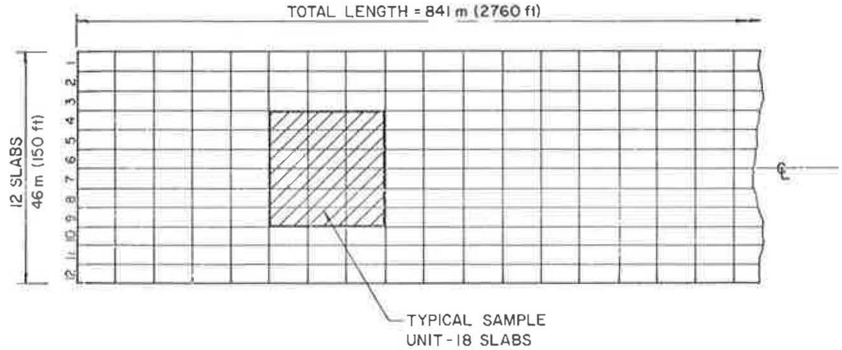
The PCI of the center six rows of slabs is 65. Thus, the feature is placed in the R-M-O zone. The outer three rows on each side of the center six rows of the runway have a PCI of 79, which places these slabs in the R-zone. Again, this supports the consideration of the center six rows as a single feature.

The M&R guidelines for the R-M-O zone state that routine or major M&R should generally be applied to pavement features in this zone unless the evaluation shows that one or more of the condition indicators is rated in a high or major category or that load-associated distresses account for a majority of the deduct values.

For this feature, the evaluation summary sheet (Figure 3) shows the following:

1. Load-associated distresses account for a majority of the deduct values,
2. Load-carrying capacity is deficient, and

**Figure 7. Layout of runway feature.**



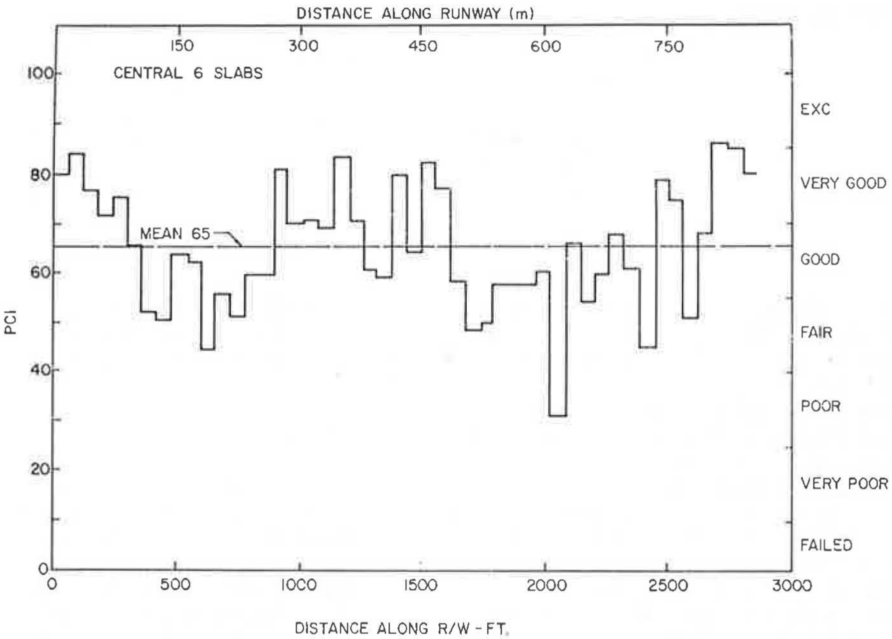



**Figure 8. PCI profile along runway feature.**

**Table 3. Summary of distresses occurring in center six rows of slabs of runway feature.**

| Cause | Type of Distress | Deduct Value | Percentage Deduct Value |
|---|---|---|---|
| Load | Corner break | 4 | |
| | Longitudinal and transverse cracking | 22 | |
| | Patching (>0.46 $m^2$) | 5 | |
| | Shattered slab | 6 | |
| Total | | 37 | 58 |
| Climate and durability | D-cracking | 2 | |
| | Joint-seal damage | 12 | |
| | Patching (<0.46 $m^2$) | 1 | |
| | Shrinkage cracking | 1 | |
| | Joint spalling | 4 | |
| | Corner spalling | 3 | |
| Total | | 23 | 36 |
| Other | Faulting and settlement | 4 | |
| Total | | 4 | 6 |
| Total | | | 100 |

Note: 1 $m^2$ = 10.7 $ft^2$.

3. Previous maintenance is excessive and rated as high.

Therefore, as the guidelines indicate, overall M&R was strongly considered and, based on these considerations, the following alternatives were selected for consideration:

1. Application of major M&R to specific distresses based on recommendations in Table 1 and field conditions,
2. Replacement of the center six rows of slabs by slabs of adequate design (keel replacement),
3. Overlaying of the entire width of the runway with concrete,
4. Overlaying of the entire width of the runway with asphalt, and
5. Performance of major M&R for a few years and then performance of either items 2, 3, or 4 above.

Each of these was considered a feasible M&R alternative. Overlaying the total width was considered only because 46 m is the minimum allowable runway width. For the same reason, if the central six rows of slabs are replaced, the outer slabs must also be maintained so as to provide an acceptable operational condition.

Each alternative has its own associated costs, downtime, and personnel and equipment needs. Thus, a comprehensive economic analysis is needed to aid in selection of the best alternative.

**Table 4. Economic analysis of alternatives.**

| Year | M&R Work Description | Cost ($) | f | Present Worth ($) |
|---|---|---|---|---|
| 1977 | Initial construction | 547 772 | 1.0 | 547 772 |
| 1982 | Joint sealing | 25 530 | 0.9108 | 23 353 |
| 1984 | Routine | 1 000 | 0.8774 | 877 |
| 1985 | Routine | 1 000 | 0.8661 | 866 |
| 1986 | Routine | 1 000 | 0.8452 | 845 |
| 1988 | Routine and joint sealing | 26 530 | 0.8141 | 21 598 |
| 1990 | Routine | 2 000 | 0.7843 | 1 569 |
| 1993 | Routine and joint sealing | 29 110 | 0.7415 | 21 585 |
| 1995 | Routine | 2 000 | 0.7143 | 1 429 |
| 1998 | Routine and joint sealing | 31 000 | 0.6753 | 20 934 |
| Total | | | | 640 828 |

Note: $r_t$ = 8 percent and $r_i$ = 6 percent.

## Economic Analysis

An economic analysis period of 25 years was selected. Table 4 shows the calculation of the total present worth of one of the alternatives, the application of a 4-cm (10-in) thick, partially bonded, no. 3 concrete overlay on the entire runway in 1977. The material costs used in the analysis were obtained from local contractors. The thickness designs of the overlays and reconstruction were determined by using Corps of Engineers design methods. Given the salvage value of the pavement as $352 560 × 0.6267 = $220 949, its present value is then $419 774.

Table 5 shows a summary comparison of all four M&R alternatives analyzed. Based on the total present worth, replacing the central six rows of slabs in 1977 and continuing routine M&R on the outside slabs (alternative 2)

**Table 5. Summary comparison of M&R alternatives.**

| Alternative No. | Alternative Description | Total Present Worth Exclusive of Salvage Value ($) | Salvage Value ($) | Total Present Worth ($) | Ratio of Cost of Alternative to Cost of Alternative 1 |
|---|---|---|---|---|---|
| 1 | Major M&R | 864 232 | 117 962 | 746 270 | 1.00 |
| 2 | Replace keel (1977) | 531 131 | 186 620 | 344 510 | 0.46 |
| 3 | Overlay with portland cement concrete (1977) | 640 723 | 220 949 | 419 774 | 0.56 |
| 4 | Overlay with asphalt cement (1977) | 649 836 | 184 848 | 464 988 | 0.62 |

is the least expensive alternative. On the other hand, performing major M&R on the central six rows of slabs and routine M&R on the outer slabs (alternative 1) is the most expensive alternative.

It should be recognized that the economic analysis was based on several assumptions. Thus, the numbers shown in Table 5 cannot be exact. The main uncertainty lies in future prediction of performance. However, the analysis does provide a reasonable relative comparison among the alternatives and makes clear that a strategy of major M&R is not the best alternative.

The results of the economic analysis should not be used as a rigid rule for the selection of the best M&R alternative; rather, they should be used as an aid to the engineer in making the selection. For example, the engineer may decide on an alternative other than replacing the keel (alternative 2) because of factors not considered in the analysis, such as available funding, runway downtime during construction, and elimination of the need for routine M&R for the outer slabs required if the keel is replaced.

## SUMMARY

This paper has introduced a procedure for evaluating the condition of an airfield pavement that has been officially adopted and is being used extensively by the U.S. Air Force. The procedure is based on a PCI that is a score between 0 and 100 and based on measured types, severities, and amounts of distress. The PCI agrees closely with the average rating (collective judgment) of experienced pavement engineers and correlates well with the need of the pavement for M&R.

The paper has also introduced a stepwise procedure for evaluation of a pavement feature and guidelines for the selection of the optimum M&R alternative. The procedure is largely dependent on the PCI and distress data. The guidelines are based on the results of the stepwise evaluation procedure and economic analysis and were developed based on the evaluation by many field-experienced maintenance engineers of 37 airfield pavements.

The use of the above procedures and guidelines is illustrated for a plain-jointed-concrete runway in Illinois.

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