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DEVELOPMENT OF A PAVEMENT MAINTENANCE MANAGEMENT SYSTEM, VOLUME X: SUMMARY OF DEVELOPMENT FROM 1974 THROUGH 1983

M.Y. SHAHIN and T.D. JAMES

U.S. ARMY
CONSTRUCTION ENGINEERING RESEARCH LABORATORY
P.O. BOX 4005, CHAMPAIGN, IL 61820

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This report documents and summarizes the development of the pavement maintenance management system from 1974 through 1983. The most important aspects of the development are discussed, step by step. These are: development of the Pavement Condition Index, development of maintenance and repair (M&R) guidelines, validation of the M&R guidelines, development of initial prediction models, development of consequence system programs, development of final prediction models, and adoption of the PAVER pavement management system.

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PREFACE

This report was prepared for Headquarters, Air Force Engineering and Services Center, Engineering and Services Laboratory, HQ AFESC/RDCF, Tyndall Air Force Base, Florida, under Reimbursable Order No. S-80-7.

This investigation was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USA-CERL) between 1974 and 1983. Dr. R. Quattrone is Chief of CERL-EM. Col Paul J. Theuer is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director. AFESC/RDCF Project Officer was Mr. James Murfee.

This technical report has been reviewed and approved for publication.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

JAMES G. MURFEE
Project Officer

ROBERT E. BOYER, Col, USAF
Director, Engineering and
Services Laboratory

L. M. WOMACK
Chief, Engineering
Research Division

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SECTION I

INTRODUCTION

BACKGROUND

The Air Force must maintain a large inventory of airfield pavements, roads, streets, and parking lots, many of which are nearly at the end of their economic design lives. Maintenance, repair, and reconstruction of these pavements cost a great deal of money--a problem when budgets are tight. Therefore, to make optimum use of these funds, it became important to identify methods for rationally determining maintenance and repair (M&R) needs and alternatives based on a comprehensive pavement evaluation. Such a pavement maintenance management system would involve describing and/or determining the relative condition of airfield pavements, developing procedures to evaluate the consequences of using various maintenance strategies to extend the service life of existing pavements, and a method of setting maintenance priorities.

In 1974, the Air Force asked the U.S. Army Construction Engineering Research Laboratory (USA-CERL) to develop a pavement maintenance management system that would ensure efficient and economical use of maintenance funds. The product was a revolutionary management method which provided: (1) a pavement condition index (PCI) for measuring the condition rating of pavements, (2) M&R guidelines, (3) prediction models, and (4) consequence system programs.

OBJECTIVE

The objective of this report is to document and summarize the development of the pavement maintenance management system from 1974 through 1983.

OUTLINE OF REPORT

The most important aspects of the system development have been summarized, step by step. Section II documents the development of the PCI, and Section III outlines the development of the M&R guidelines. Section IV summarizes the validation of the M&R guidelines. Section V documents the development of the initial prediction models, Section VI discusses the consequence system programs, and Section VII outlines the improvement and verification of the prediction models. Section VIII deals with the adoption of PAVER for Air Force use.

SECTION II

DEVELOPMENT OF THE PAVEMENT CONDITION INDEX

PREVIOUS PAVEMENT CONDITION SURVEY PROCEDURES

Formerly, Air Force personnel performed concrete pavement condition surveys by visually examining pavement facilities. This system had two major disadvantages:

1. Distresses were identified by type without considering severity.

2. The determination of a pavement feature's condition, based on percentage of slabs containing no defects or no major defects, was inadequate.

In addition, the Air Force had no objective technique for assigning a condition rating to asphalt- or tar-surfaced pavements. These pavements were being visually inspected for distress, rated subjectively, and classified in three very broad categories: good, fair, or poor. The results of Air Force surveys correlated with average engineering ratings only when the pavement condition was very good or excellent; in other cases, the Air Force results were usually underrated.

AIRFIELD PAVEMENT DISTRESS ANALYSIS

Development of a pavement condition index (PCI) required identification of all types of pavement distresses. On jointed concrete pavements, the distress types found were blow-up, corner break, longitudinal/transverse/diagonal cracking, "D" cracking, joint-seal damage, patching, patching/utility cut, popouts, pumping, shattered slab, shrinkage cracking, joint spalling, and corner spalling. The most common distress types were longitudinal/transverse/diagonal cracking, scaling/map cracks/crazing, and patching. All distress types occurred at various severity levels.

On asphalt- or tar-surfaced pavements, the distress types found were alligator cracking, bleeding, block cracking, corrugation, depression, jet blast, joint reflection from PCC, longitudinal and transverse cracking, spillage, patching, polished aggregate, raveling/weathering, rutting, shoving from PCC, slippage cracking, and swelling. The most common distress type was block cracking, and all distress types occurred at various severity levels.

THEORY BEHIND PCI DEVELOPMENT

A comprehensive pavement evaluation requires measurement of several condition indicators, including roughness, skid-resistance, structural capacity, and surface physical deterioration or distress. However, direct measurements of these indicators require expensive equipment and personnel, so these measurements cannot be made routinely. However, considerable field experience has shown that observation of existing distress will provide a useful index of current pavement condition and can indicate future performance under current traffic conditions.

The degree of pavement deterioration is a function of types of distress, severity of distress, and amount or density of distress. Combining the effects of these characteristics into one index was the major problem in the PCI development. The method chosen as best for expressing a condition index was based on the assumption that pavement condition can be accurately estimated by summing all visible distresses over their severity and density levels, using deduct weighting values for each characteristic.

The most difficult aspect of PCI development was determining the deduct weighting values. To avoid time-consuming, expensive field-test measurements, the collective opinion of experienced engineers was used to develop reasonable deduct values. This type of subjective approach required careful planning, and then had to be field-tested, evaluated, and revised. The PCI developed is a numerical rating ranging from 0 to 100, which provides a measure of airfield pavement structural integrity and surface operational condition.

PCI FOR JOINTED-CONCRETE PAVEMENT

Based on a literature review, condition surveys for more than 20 airports, and firsthand observations, an initial set of distresses was selected and severity levels were defined. Deduct values were set by subjectively estimating the maximum deduct for each distress and severity level at a maximum density and then assuming a curvilinear relationship between the deduct value and density. The initial procedures developed in this manner were then field tested and each section was given a PCI. Base pavement engineers then provided subjective pavement condition ratings. The average of their ratings was computed and called the pavement condition rating (PCR). An evaluation of results revealed two major deficiencies:

1. The definitions of several distress types and levels of severity did not adequately describe the actual conditions.

2. The calculated PCIs were much lower than the average subjective conditions estimated by engineers.

As a result, the procedures were revised extensively and then field-tested again.

The second field-test evaluation revealed the same deficiencies observed in the first test. This result led to the conclusion that a correction factor would have to be used. It was now obvious that deduct values could not simply be added together when more than one distress type occurred in one pavement section, since the deduct value curves were derived for only one distress type. Analysis showed that the total deduct value for a pavement section must be adjusted to reflect the number of deducts and the magnitude of the total deduct value. The adjustment factor was determined by subjectively rating several pavement sections which each had two to eight types of distresses and/or levels of severity. The correction curves derived provided significantly improved estimates.

A third field test was then conducted and the results showed that nearly all distresses were now adequately defined and that the calculated PCI now correlated well with estimated ratings. Thus, it became obvious that clear and complete descriptions of distress are essential to a successful pavement condition rating. Also, correct deduct values cannot be assigned unless the distress is adequately identified and defined.

The revised procedure was then validated in the field at four airfields, and a few deficiencies were identified and corrected. Analysis of the data showed that the final procedure provided a 95 percent confidence that the PCI is within ± 5 percent of the average condition rating (PCR) and is, therefore, a reliable pavement condition-rating technique.

PCI FOR ASPHALT- AND TAR-SURFACED PAVEMENTS

Literature on asphalt pavement distresses was reviewed and pavement observations were made; this information, along with previous experience, was used as a basis to select an initial set of distresses and to define severity levels for asphalt- and tar-surfaced pavements. A discrete method was used for density of distress, rather than the continuous curve used for concrete pavements.

The initial procedure was field-tested on four asphalt-surfaced pavements. Each section was surveyed and a PCI was computed for each. Experienced pavement engineers then subjectively rated each pavement section. The evaluation results revealed two major deficiencies: (1) the definitions of several distress types and levels of severity did not describe actual conditions adequately and (2) the calculated PCI of two of the sections was reasonably close to the PCR, but for the other two, was considerably different.

Based on this field test, the procedures were extensively revised. The deduct value curves were revised for each distress type at a particular level of severity according to the following procedure: (1) experienced engineers rated the pavement subjectively, (2) these ratings were made for four or five levels of density, and (3) the mean of the subjective ratings was computed for each density level. A plot of the density of distress versus the mean deduct value was then developed and a best-fit smooth curve was fit through the points. This procedure was done for each of the 16 distress types and for one to three severity levels for each type. The procedures were revised and field tested again.

The second group of field-test results indicated that some of the definitions did not clearly describe existing distresses and that the PCIs for several sections containing several distress types were much less than the PCRs. As a result, several of the definitions were revised to reflect experience gained from the field testing. As with the PCI for concrete pavements, it was thought that deduct values could not be added together when more than one distress type occurs in a pavement section. Thus, a condition factor had to be derived. Total default value would have to be adjusted to reflect the number of deducts (or distress types plus level of severity) and the magnitude of the total deduct value.

This adjustment function for multiple distresses was determined by subjectively rating many pavement sections containing from two to six distress types and/or levels of severity. The sums of the calculated deduct values and the corrected deduct value were then plotted.

A third field test was then conducted on 17 pavement sections. Evaluation results indicated that nearly all of the distresses were adequately defined and that the calculated PCI values corresponded closely with the mean PCR ratings for each section. The multiple distress curves improved the procedure greatly.

The revised procedure was then validated in the field at three airfields, and a few deficiencies in distress definitions and deduct curves were identified and corrected. Analysis of the data showed that the final procedure provided 95 percent confidence that the PCI is within $\pm$ 4.75 of the average condition rating (PCR) and is, therefore, very reliable.

PAVEMENT INSPECTION PROCEDURES

Determining the PCI requires an ability to measure all distress on a pavement surface, including the type, severity, and amount of distress. Therefore, guidelines for inspecting pavements were drawn up, along with sampling procedures.

Jointed-Concrete Pavement Inspection

The pavement is first divided into features based on its design, construction history, and traffic area. These features should then be outlined and identified on the airfield layout plan.

To inspect an individual feature, it is divided into "sample units" of about 20 slabs, with each numbered for future inspections or maintenance needs. Each "sampling unit" is inspected and its PCI calculated. Distresses are recorded and their severities noted. After obtaining an accurate distress count, the distresses are summarized and the severities of each are compiled. The PCIs are also summarized.

Asphalt- and Tar-Surfaced Pavement Inspection

As with concrete pavements, the pavement is divided into features based on its design, construction history, and traffic area. In this case, condition of the pavement (based on observable distress) is also a consideration. The feature is then outlined and defined.

For inspection, a feature is divided into "sample units" of about 5000 square feet of surface area and numbered. Each unit is inspected, measuring each distress type and its severity and recording the data. The total distress data are used to calculate the PCI of the section. The PCIs are then summarized.

SAMPLING PLAN

A sampling plan was developed to minimize the engineer's time and effort for inspection, yet still provide an accurate assessment of pavement condition. To use the plan, the feature is subdivided into several sample units of about 20 slabs (for concrete) or 5000 square feet (for asphalt or tar). The number of sample units needed to adequately estimate PCI depends on how large an error can be tolerated in estimating the mean feature PCI, the desired probability that the PCI estimate will be within this limit of error, an estimate of the variation of the PCI among samples within the feature, and the total sample units in the feature. Volume V of this report (Paragraph 3-5) provides information on determining sample units.

Samples are selected, using a systematic random technique where the first unit is selected at random and the remaining units are selected at equal intervals. The sample unit of the feature is computed by averaging the PCIs of all surveyed units.

BENEFITS OF USING PCI

The PCI is an accurate and objective tool for airfield pavement condition rating. A calculated PCI agrees closely with the mean pavement condition rating (PCR) obtained by averaging the individual ratings of experienced pavement engineers. Pavement condition rating, based on PCI, is much more consistent than individual subjective ratings since it is based on measured distress data and not on subjective judgment. Determining the PCI of a pavement does not require special equipment. In addition, this method minimizes inspection time and reduces inspection costs, since only a portion of a pavement feature has to be inspected. The PCI can be used effectively to determine M&R requirements and to provide accurate and objective measurements of pavement structural integrity and surface operational condition. It gives major commands a common index for comparing the condition and performance of pavements and provides a rational basis for assigning priorities for in-depth pavement evaluations.

SECTION III

DEVELOPMENT OF M&R GUIDELINES

The first step in determining optimum M&R for a given pavement feature is an accurate, comprehensive evaluation of a pavement's current condition. Airfield pavement condition depends on several indicators which must be measured. These include: (1) operational surface indicators (roughness, skid resistance, foreign object damage potential), (2) structural indicators (structural integrity and load-carrying capacity), and (3) other indicators, such as rate of deterioration and amount of previous M&R applied. Based on these measurements, feasible M&R alternatives can be selected.

Several M&R alternatives can be used to restore the structural integrity and/or operational condition of a pavement feature. However, there were no guidelines for determining the most economical alternatives and repair priorities based on existing pavement feature condition. One reason for this was the lack of a comprehensive pavement condition indicator related to maintenance requirements. Development of the PCI has removed this deterrent and allowed development of tentative guidelines relating PCI to the M&R requirements.

A rational procedure was developed for determining M&R requirements. In the first step, the engineer performs the pavement condition survey and calculates the PCI. It should be ascertained at this time whether the rate of deterioration is normal. It should also be determined whether there will be a change in traffic mission, whether there is a structural deficiency, whether there have been pilot complaints about long-wave roughness, or whether there is a skid hazard, none of which can be directly measured by the PCI. If these factors are not apparent, the appropriate M&R category can then be selected based on the value of the PCI. Priorities are then established, based on the value of the PCI and the use of the pavement feature.

M&R CATEGORIES

M&R methods can be grouped into three general categories:

1. Routine M&R, which consists of preventive and/or localized M&R. This includes methods that preserve pavement condition and retard its deterioration, such as crack or joint sealing.

2. Major localized M&R, which is a more extensive form of localized M&R. This includes patching, slab replacement, and undersealing.

3. Overall M&R, which covers the entire pavement feature and usually improves its load-carrying capacity. This includes overlay or total reconstruction.

DETERMINING M&R REQUIREMENTS

Recommended methods for repairing individual distresses were developed from the results of questionnaires sent to field engineers. For a given distress type and level of severity, more than one repair method may be recommended; selecting th appropriate method is left to the discretion of the engineer, depending on field conditions encountered.

Selecting the proper M&R category for a pavement feature is a major decision requiring years of experience in pavement M&R. The decision depends on many factors, including PCI, rate of deterioration, causes of deterioration, pavement load-carrying capacity, hydroplaning potential, previous M&R, and past/current/future traffic, mission, and costs.

M&R guidelines were developed for selecting an M&R category for an airfield pavement feature based on its PCI. The correlation of the PCI with M&R categories was based on results obtained from 37 airfield pavement features, using the collective judgment of 10 experienced pavement engineers. The features consisted of primary runways, taxiways, and aprons, and represented a wide variety of climates, traffic ages, and structure. Eighteen of the features were asphalt- or tar-surfaced pavements, and 19 were jointed concrete.

An analysis was conducted using the data from these pavement features, and the PCI for each pavement feature versus the percentage of engineers recommending routine, major, or overall M&R within the next 2 years. For any given feature, the sum of the percentage of engineers recommending the three M&R categories added up to 100 percent. The results showed that the higher the PCI, the greater the percentage of engineers selecting only routine M&R. The lower the PCI, the greater the percentage choosing overall M&R. In the middle of the PCI scale (40 to 70), there was a lack of consensus. Major, localized M&R was chosen most often for PCIs from 25 to 70, but rarely above or below these limits.

Based on these results, four M&R zones were established to provide guidelines for selecting M&R:

1. Routine M&R zone, which included all pavement features having PCIs between 71 and 100, or a condition rating of very good or excellent. The specific M&R methods were determined, based on distress types and severities. Major or overall M&R would be recommended only in exceptional cases.

2. Routine-major-overall zone, which included all pavement features having PCIs between 41 and 70, or a condition rating of fair or good. Generally, the higher the PCI in this zone, the higher the percentage of engineers recommending routine M&R. The specific routine or major M&R selected depended on the type of existing distress and severities. Overall M&R would be considered only if the condition evaluation indicated that a specific type of distress or deterioration existed.

3. Major-overall zone, which included all pavement features with PCIs between 26 and 40, or a condition rating of poor. The consensus for this category was that pavement features in this condition receive either major or overall M&R within the next 2 years. The decision to select major or overall M&R would be based primarily on an economic analysis of the alternatives, and

on whether one or more specific distress types existed. The economic analysis would consider the major M&R alternatives and one or more overall M&R alternatives.

4. Overall zone, which included all pavement features having PCIs between 0 and 25, with a condition rating of very poor or failed. The consensus was that pavement features in this category would receive only overall M&R within the next 2 years. It was felt that pavements in this condition were beyond the point of economical repair and that only an overall M&R would provide adequate results.

The correlation between these four M&R zones and the PCI condition ratings provides a convenient way to plan M&R work. The airfield pavement engineer should develop a large map that outlines each feature of the airfield. As the condition survey is conducted and the PCI of each feature is determined, it is recorded on the map. The condition rating of each feature should then be color-coded. Thus, since the M&R zones correspond directly to these ratings, the engineer can immediately identify the M&R zone for each feature of the airfield.

ECONOMIC ANALYSIS OF M&R ALTERNATIVES

Based on the results of the pavement condition evaluation and the M&R selection guidelines, the engineer may have to consider more than one M&R alternative. Selecting the best alternative often requires an economic analysis to compare the costs of all feasible alternatives. A procedure was developed which compares M&R alternatives based on total present worth.

This economic analysis procedure provides a means of comparing various M&R alternatives based on present costs. However, M&R alternatives provide different levels of pavement performance, so a preliminary economic analysis procedure was developed that would consider pavement performance. This procedure considers PCI history over time. Instead of comparing alternatives on present worth alone, it compares them on the basis of weighted performance per dollar per square yard (i.e., how much performance is obtained for each dollar spent). The weighted performance is obtained by calculating the area under the PCI-versus-time curve for the analysis period and weighting this area based on the importance of the pavement feature.

A complete explanation of these procedures is provided in Sections VII and VIII of Volume VIII.

SECTION IV

VALIDATION OF M&R GUIDELINES

The preliminary M&R guidelines and economic analysis procedure were field-tested, validated, and revised in order to provide an improved procedure for selecting optimum M&R alternatives. The procedures were tested in several field applications. Many pavement features at various Air Force bases were surveyed, feasible M&R alternatives were identified, and an economic analysis performed to select the ᑊ st alternative.

ASPHALT RUNWAY CASE

The pavement used for this portion of the field testing was an asphaltic concrete (AC) runway located in North Carolina. One of the features surveyed was divided into two sections, each 750 feet long by 150 feet wide, because of a large difference in PCI. One section had a PCI of 81, and the other had a PCI of 51. Pavement core samples indicated that the portion having the higher PCI was 7.5 inches thick, while the other portion was only 5 inches thick.

Several M&R alternatives were considered for the section having a PCI of 51, with recycling selected as the most economical. Use of the improved procedures for selecting M&R saved the Air Force a great deal of money in this case, because the cost of repairing a section 750 feet long by 150 feet wide was saved. Originally, the whole section was scheduled for M&R. The decision not to repair a portion of the runway was based on an in-depth engineering analysis (Volume VI) triggered by the high PCI value. In addition, considerable savings also resulted when only part of the runway had to be closed down for repairs. If the entire feature had been closed for M&R, runway length requirements would have necessitated diverting aircraft to other airfields, which would have cost the Air Force millions of dollars.

CONCRETE APRON CASE

The pavement used for this section of the field testing was a concrete feature of an apron located in Louisiana. The KC-135 and B-52 were the primary aircraft using the pavement.

The mean PCI for the feature was 70, which corresponded to a condition rating of "good." However, there was considerable variation in PCI among sample units. Key structural distresses were identified as corner breaks, longitudinal and transverse cracking, and/or shattered slabs. Most of the distress occurred along the traffic lines.

The feature was classified for routine or major maintenance, and possibly overall repair. In this case, the load-carrying capacity was determined to be deficient, and the load-associated distress contributed 88 percent of the total deduct value. Therefore, overall repair was considered a feasible alternative. Based on the evaluation results, four feasible alternatives were identified and an economic analysis performed for each:

1. Perform localized repair as needed

2. Reconstruct traffic area and perform localized repair as needed

3. Replace shattered and severely cracked slabs and overlay with 7-inch fully bonded concrete pavement

4. Replace shattered and severely cracked slabs and overlay with 10-inch, partially bonded PCC.

The analysis showed that Alternatives 2 and 3 were the most economical. Also, Alternative 2 had the advantage of a lower initial cost. Adoption of Alternative 3 would also require special adjustments in the floors of the B-52 maintenance hangars. However, with Alternative 2, aircraft movements would have to be limited to the markings on the pavement. The base engineer decided to base M&R on Alternative 2.

SECTION V

INITIAL PREDICTION MODELS

To select the most economical M&R methods, the engineer must have extensive knowledge about the consequences of applying various M&R alternatives, as well as the consequences of not applying any M&R. This requires the ability to predict future pavement condition; however, this is very difficult because designs, materials, climates, subgrades, repair alternatives, and amounts of traffic vary.

Efforts to develop analytical methods of predicting pavement condition proved that it was feasible to predict condition using probabilistic theory and empirical models developed from field data. Pavement condition was defined as the trend of PCI over time and the development of major distress types over time. Thus, if PCI and major distress types can be reasonably predicted over a future time period for a variety of pavement situations, the consequences of various M&R alternatives can be predicted.

The types of questions that M&R consequence models should be able to answer about a given pavement feature are:

1. If only routine maintenance is applied over the next x number of years, what are the consequences in terms of PCI, distress occurrence, costs, and downtime?

2. If particular types of major maintenance are applied, what are the consequences?

3. If an overlay or recycling is performed, what are the consequences?

4. If a mission change occurs, what are the consequences of applying or not applying specific M&R?

The use of consequence models demands the gathering of considerable data and many computations. Thus, it was necessary to study the feasibility of developing a pavement maintenance information system. Such a system would ensure expedient access to the data required for using the consequence models and for performing other management requirements such as project validation, estimation, and optimization.

Initial work in developing this type of system involved:

1. Developing models for predicting the PCI of asphalt and concrete pavements, including both asphalt and concrete overlay, using available data

2. Determining information requirements for pavement management

3. Providing alternatives for implementing a computer-aided pavement management system.

To carry out these objectives, data collected for the PCI development were used. Multiple regression techniques were used to develop prediction models for PCI and distress, using this data base. Sensitivity analyses were conducted to determine the usefulness of the models.

CONCRETE PAVEMENT PREDICTION MODEL

A regression model was developed with the following variables:

1. Age since original construction or overlay
2. Ratio of interior slab stress to modulus of rupture
3. Slab replacement
4. Slab size
5. Asphalt overlay
6. Average annual temperature
7. Freezing index
8. Patching.

The model was constrained so that it would fit the important boundary condition of PCI = 100 just after initial construction or overlay.

The stepwise regression procedure used in the model development starts with the simple correlation matrix between the PCI and each variable, and enters into regression the independent variable most highly correlated with the dependent variable (PCI). Using partial correlation coefficients, it then reflects the next variable to enter regression, i.e., that variable whose partial correlation with PCI is highest. At every step, the procedure reexamines the variables included in the equation in previous steps. Thus, some variables may be removed from the equation after they have been entered.

The more independent variablesthat enter the equation, the better the equation will fit or model the data for predicting PCI. However, after a certain point, the effect of additional variables in terms of increasing the R^2 or decreasing the standard error will be insignificant.

ASPHALT PAVEMENT PCI PREDICTION MODELS

The objective of these models was to forecast the condition of pavement for a variety of possible future M&R alternative actions and/or mission changes. The models will be used in making decisions about airfield mission changes, determining budget requirements, and optimizing maintenance funds.

The development of the model was based on data from 26 AC pavements that did not have AC overlays, and 11 which had AC overlays. In developing the models, all variables were interacted with age since construction or last overlay to ensure that, at age equal to zero, the PCI is equal to 100. Climate and previous maintenance were not represented in this model. The variables used were:

1. Age since original construction or last overlay if the pavement has been overlaid.

2. Load repetition factor determined at the subgrade level.

3. Age between the time the pavement was constructed and the time it received the last overlay.

4. Total AC thickness in inches, including overlay, if any.

5. Load repetition factor determined at the AC base.

In using the model, the effects of each variable were:

1. Subgrade CBR: The rate of pavement deterioration decreases as the value of the subgrade CBR increases.

2. Base CBR: As the base CBR increases, the PCI increases.

3. AC Surface Thickness: The rate of pavement deterioration decreases as the pavement thickness above the subgrade increases. Thus, the increase in pavement thickness is attributed to the increase in the base and the subbase thickness combined.

4. Time Between Original Construction and Overlay: The longer the time between original construction and overlay, the lower the PCI at any specific time after the overlay (i.e., the longer the time before an overlay is placed, the faster the rate of deterioration after its placement.

Volume VII presents a complete description of the models which are currently programmed in the PAVER system.

SECTION VI

CONSEQUENCE SYSTEMS PROGRAMS

Several of the engineering procedures presented in the previous sections were computerized in a user-oriented interactive system called the Airfield Pavement Management System (APMS). Each program in the system was called a module. These modules are: Evaluation Summary Module (EVALSUM), Localized Repair Analysis Module (ANALOC), Consequence of Overall Repair Module (CONOMR), Cost Computation Module (COSCOM), Benefit Computation Module (BENCOM), and Budget Optimization Module (BUDOPT). Each of these modules was later incorporated into the Paver Pavement Management System. Volume VIII provides detailed information on each of the modules. Following is a brief description of each.

EVALUATION SUMMARY MODULE (EVALSUM)

This module provides a list of feasible, general M&R alternatives from which the user can make specific choices about a given pavement feature. The user inputs information for the condition evaluation summary. This information is then processed through performance standards tables, and the M&R alternatives are produced.

Inputs to EVALSUM are the PCI and condition evaluation summary data for a given feature. These data provide enough information to generate a preliminary list without considering features peculiar to individual projects.

The first step in developing the module was to select a set of alternatives that would provide the engineer with a sound base for which a set of options for a specific project could be conceptualized. Fourteen alternatives were selected, such as reconstruction, routine maintenance, and surface treatment. A performance-tables concept was developed to combine data from the condition evaluation summary and generate a list of alternatives. The tables were constructed by considering a typical pavement feature in a given M&R zone and then placing the M&R alternatives that would be considered for each item on the evaluation sheet. Next, the EVALSUM module was developed. For a given set of input data, the module determines the list of feasible M&R alternatives as follows:

1. The appropriate performance standards table is selected based on the PCI value input.

2. A list of the possible M&R alternatives is developed from the table based on the evaluation summary inputs.

3. A list of infeasible alternatives is compiled.

4. The infeasible alternatives are removed from the feasible list.

5. The remaining alternatives are output as the recommended maintenance options.

LOCALIZED REPAIR ANALYSIS MODULE (ANALOC)

The localized repair analysis module computes both the cost of a given localized repair policy and the PCI after repair. This allows the user to compare localized repair alternatives on the basis of their effect on cost and condition. The distress data from the condition survey are input as a sample unit. This information is then stored in a file and used by the module for cost and PCI calculations.

The ANALOC module works on a pavement feature basis. For a given feature, the system computes the PCI before repair and cost estimates for the repairs. A condition survey is performed on the pavement feature, and each sample unit's distress data are input to the module. The data are then processed through the PCI program. The data can be processed without modification to produce a PCI before repair, or it can be processed in combination with built-in M&R distress policy tables. The module allows the user to modify, temporarily or permanently, all built-in tables. The M&R policy routine produces a report which gives a breakdown of costs for each distress repaired and a total cost estimate. The distress-after-repair policy replaces the original distresses with those resulting when a repair is applied, or eliminates the distress after the repair. The new distress types are inserted in the PCI calculation program, and a report is generated which gives the new PCI and estimated quantities of distress. The impact of the localized repair on the pavement condition and the associated costs is obtained from these reports.

CONSEQUENCE OF LOCALIZED REPAIR MODULE (CONLOC)

This module augments the information obtained in the localized repair analysis and is used to predict the PCI change with age after localized repair. This allows analysis of various localized repair alternatives.

The CONLOC module is used to project the PCI over time for a given pavement feature after localized repair. The best method to predict the life of localized repair is a straight-line extrapolation of the PCI time curve. For example, if a localized maintenance activity was applied which raised a pavement's PCI, the future PCI could be estimated by extrapolating the PCI time line, at the same slope as the original, from the PCI after repair. If the PCI has been determined previously, the slope of the PCI time line between the previous PCI and the present PCI can be computed. This slope can then be compared with that of the PCI time line, using the PCI at original construction, or the last overlay and the current PCI. The greatest slope helps predict the PCI after the repair.

Another option available in the CONLOC module is to consider the "do nothing" alternative. This option allows the user to compare the other alternatives with the performance of the pavement if no maintenance was performed.

CONSEQUENCE OF OVERALL REPAIR MODULE (CONOMR)

This module is used to predict the performance of overall repair alternatives. It can also be used to predict the future performance of a new pavement feature, or of an existing one, if overall maintenance is not done.

CONOMR is a computerized package of prediction models. Separate PCI prediction equations were developed for asphalt concrete and portland cement concrete pavements. Predictions can be made for overall or major repairs, or for the "do nothing" alternative.

The concrete prediction model is used to analyze both concrete and asphalt-over-concrete pavements. The asphalt concrete prediction model is a combined model that can be used to analyze pavements which have or have not been overlaid previously.

COST COMPUTATION MODULE (COSCOM)

This module is used to perform life cycle cost analyses on M&R alternatives selected for possible use on a specific feature. The cost analysis used includes a present-value analysis which provides the total cost of the alternative adjusted for interest and inflation rates. Also, an equivalent uniform-annual-cost analysis is computed; this distributes the cost annually over the life of the alternative.

A decision maker uses several types of costs to evaluate the best M&R alternative for a given pavement feature. These include:

1. Initial cost of the alternative (first-year cost)

2. Present value of the alternative (discounted cost of the alternative in present dollars, using interest and inflation rates)

3. Equivalent uniform annual cost of the alternative (present-value cost converted to an annuity)

4. Equivalent uniform annual cost per square yard of pavement.

The initial cost is the present annual cost of the alternative, disregarding any future costs. In economic analyses, the effects of interest and inflation rates are usually taken into account. The inflation rate is used to adjust the future cost of an M&R alternative. To consider all dollar figures equivalently, it is common practice to reduce all future costs to their present value by applying an interest rate discount. In most cases, an M&R alternative consists of a series of M&R activities with associated costs. The present value of a series of M&R costs is found by adding the initial cost to the present value of all future costs adjusted for inflation and interest rates.

The present-value analysis is a convenient tool in the decision making process because it allows choices to be made in terms of present dollars. The user can avoid comparing present dollars with dollars several years in the future.

Each M&R alternative being considered for a given feature requires a different sequence of M&R activities. Two types of cost inputs account for these activities:

1. Anticipated one-time costs--a listing of the initial and future anticipated M&R activities. Each activity, its estimated costs, and its timing are input.

2. Anticipated periodic costs--costs for M&R activities to be performed at regular intervals over the life of the alternative.

BENEFIT COMPUTATION MODULE (BENCOM)

This module provides a method for calculating the benefits of a given M&R alternative in terms of its weighted performance. The benefit of an alternative is calculated using the following parameters:

1. Area under PCI time curve

2. Utility values

3. Relative weights for feature type

4. Minimum PCI for the feature.

The benefit calculated in this module and the cost data from the cost computation module are then used as input to the budget optimization module.

For this module, benefits are defined with three nonmonetary criteria: (1) maintenance of a high pavement condition rating, (2) type of facility, and (3) level of PCI. These criteria are included in the module to compute the benefit derived from a given M&R alternative.

Certain benefits can be derived from doing nothing to a feature if the current level of PCI is above the minimum. Generally, the benefits are calculated differently, depending on whether the current value of the PCI is above or below the minimum PCI.

1. Current PCI at or below minimum PCI--benefits are the total area between the utility-weighted PCI versus time curve for a new M&R alternative and the current PCI value.

2. Current PCI above minimum PCI--benefits are the total area above the minimum PCI line and the "do nothing" PCI versus time curve, and below the utility-weighted PCI versus time curve for a new M&R alternative.

Relative utility-weighted benefits may be calculated for each M&R alternative considered for each feature. A decision maker can then choose the M&R alternative which produces the maximum benefit within the budget allocated for a feature.

To have a consistent basis for comparison, costs and benefits must be computed on an annual basis. This can be done in two ways: (1) the linear method and (2) the capitalized benefit method. The method selected will depend on whether the decision maker views benefits as independent of interest and inflation rates, or as roughly proportional to the dollar value of keeping a feature in service.

The module gives default values to relative weights, utility curves, and minimum PCI values. The user may change these values either temporarily or permanently.

BUDGET OPTIMIZATION MODULE (BUDOPT)

This module maximizes the benefits gained from budget dollars. Using the cost and benefit figures for several M&R alternatives per feature, the module performs calculations which select, for a group of pavement features, the set of M&R alternatives maximizing the benefits for a given budget.

To select the best M&R alternative for a feature, the module requires:

1. Upper budget limit for the feature

2. Initial cost of each alternative

3. Life cycle cost of each M&R alternative

4. Benefit of each M&R alternative.

To select the best M&R feature in an M&R program, BUDOPT must have:

1. Total budget

2. M&R alternative information for each feature, including alternative identifier, equivalent uniform annual cost, annual benefit, and initial cost of alternative.

The module then uses an incremental benefit/cost algorithm to determine the best M&R alternative for each feature. The algorithm ensures that the maximum benefit is achieved within the total budget available for the overall M&R program.

SECTION VII

IMPROVEMENT AND VERIFICATION OF PREDICTION MODELS

The early prediction models (see Volume VII) showed that more comprehensive models could be developed if a broader data base was available. As a result, a comprehensive data collection effort was begun in FY 80. Extensive data were collected from in-service Air Force pavements over typical ranges of design materials, traffic, and climate. The data were used to begin developing improved PCI and distress models for asphalt and concrete pavements and to verify the new models.

The data were collected for 327 airfield pavement features located throughout the United States. More than 150 pieces of information were collected from each feature. The data were checked, computer processed, and prepared for analysis. Multiple regression techniques were selected for developing PCI and key distress prediction models using this large data base. More data were then collected for 101 of the previously surveyed features and used to evaluate the prediction models.

DATA COLLECTION

Computer-coded data collection sheets were prepared to provide uniformity and ease of data collection and processing. Variables were then chosen that were believed to affect pavement performance, with the objective of obtaining a complete historical set of information about each pavement feature, including:

1. Feature identification
2. Pavement layer information
3. Joint design for concrete pavements
4. Foundation soils
5. Traffic for each mission
6. Past maintenance
7. Current PCI and distress.

An average of 27 features were obtained for each base. The features were divided into several pavement types: PCC, PCC over PCC, PCC over AC, AC, AC over PCC, AC over AC, and other. Several mechanistic variables were also computed, including edge stress for concrete slabs and radial strain at the bottom of the original asphalt layer, vertical stress on the base course, surface deflection, and vertical strain on top of the subgrade for asphalt pavement.

The data were coded on forms, checked, and computer-processed. Converted data were then keypunched and read into a computer disk file for use with the Statistical Package for Social Science (SPSS). Means, frequencies, and other statistics were obtained to further verify the reasonableness of the data.

CONCRETE PAVEMENT PREDICTION MODELS

Extensive work was done to develop prediction models for specific distress types. All models were developed in two distinct phases. The first phase was development of a linear regression model with as high an R^2 as possible. The second phase was use of the developed linear model as a starting point for nonlinear regression analysis. The SPSS statistical package was used in all development phases for all the models.

PCC and AC/PCC PCI Model

A model was developed for predicting the PCI for both PCC pavements and PCC pavements overlaid with asphalt. Using a transformed section analysis for stress determination, the AC/PCC pavement features were combined with the PCC pavement features, and a PCI prediction model was developed to include both. Data for the model were collected for 162 pavement features: 137 PCC pavements and 25 PCC pavements overlaid with asphalt.

Numerous stepwise regression analyses were performed using different variable combinations and interactions. Variables picked for regression analysis were selected using correlation matrices between variables and the PCI. Scattergrams revealed ranges and general trends of the variables. Partial correlations of other variables were then studied and the procedure continued. Results of each regression analysis were analyzed and new combinations and interactions of variables chosen. A sensitivity analysis was performed on the regression models that looked promising.

After many attempts, the best linear regression model was selected, based on combined statistical and engineering criteria. This was the Phase 1 model, which was used as a starting point for nonlinear regression analysis. For Phase 2, the functional form of the Phase 1 equation was input, using all coefficients and power functions as variables.

Initial values were assigned to the variables and limits placed on the values. The results from early nonlinear regression and the resulting trends of the values of the variables were analyzed, and the influence of the individual variables on the dependent variable (PCI) was evaluated. Sensitivity analyses were run to ensure that the model continued to meet various engineering criteria.

All models were evaluated according to the following criteria:

1. Are the coefficients reasonable?

2. How sensitive is the model to factors affecting the PCI?

For this model, all of the coefficients were negative, so that as any of the values of the variables increase, the PCI should decrease. This is reasonable because all the variables are defined so that, if they increase, the eventual pavement deterioration will also increase.

The equation would represent a realistic situation if all the factors involved in pavement deterioration and its eventual PCI were included in the equation in its proper functional form. A sensitivity analysis shows that the model was adequate for the factors of traffic and pavement structure, foundation, and environment, but inadequate for the factors of material properties and maintenance.

Corner Break Model

A model was developed to predict corner breaks for concrete pavements which used data from 137 nonoverlaid PCC pavements. The first step in developing the model was to create and study several correlation matrices of possible prediction variables. Based on these matrices, variables and variable combinations that looked promising were studied further. Trends of variables were studied to detect possible power functions of variables that could be made better predictors. Preliminary linear regression models were made and studied to find how variables would interact once they were actually in a prediction model. All early work pointed to a model easily influenced by the mechanistic fatigue variables, and by the age and thickness of the pavement.

As with the PCI prediction model, the linear model was used as a starting point for nonlinear regression analysis. Limits were put on the values that the variables may take. The computer then picked values for the variables that would minimize the error.

An evaluation of the model showed that the model predicts the higher distress amounts well, but is less accurate at the lower distress levels. The signs of all the variables entered in the equation are positive, showing that as the value of any variable increases, the amount of corner breaks will also increase. This is reasonable because two of the variables are indicators of the amount and type of traffic the pavement has serviced. The equation would be plausible if all the variables that affect corner breaks were included in the proper functional form. A sensitivity analysis showed that the model was adequate for the factors of traffic, slab dimensions, foundation, joint design, and material properties, but not for construction or environment.

ASPHALT PAVEMENT PREDICTION MODELS

The data for asphalt and asphalt-overlaid asphalt pavement were collected during FY 80 and checked with new data collected during FY 82. Models for predicting joint reflection cracking and alligator cracking were also attempted.

AC and AC/AC PCI Model

A model for predicting the PCI for asphalt and asphalt/asphalt pavements was developed using data collected for 69 asphalt pavement features: 26 non-overlaid pavements, and 43 with one or more asphalt overlays.

In developing the model, extensive use was made of the elastic layer theory computer program developed by Shell Oil Company. The program was used to determine the stress levels, strains, and deflections caused by particular aircraft/pavement combinations. These stress and deflection determinations were combined with knowledge of the total traffic amounts, and cumulative mechanistic variables were created. These variables record the amount of asphalt pavement fatigue based on stress levels, strains, and deflections that different aircraft cause.

Early research showed that the variable of age was a very good predictor of PCI for asphalt pavements. Combinations of age with other variables, both environmental and mechanistic, were evaluated. Several models were created and tested, and the best was chosen.

In evaluating the model, analysis showed that above a value of about 50, the model did very well in predicting PCI. Below 50, the model tended to predict PCIs a little higher than they actually were; however, the overall results were very encouraging. The coefficients in this model are all negative. Thus, increases in age, age before overlay, traffic before overlay, or average size of traffic should cause a lower PCI, and the model reflects this. A truly realistic model would result if all the variables that affect the PCI of asphalt pavements were included in their proper functional form. A sensitivity analysis showed that the model was adequate for the factors of traffic and pavement structure and foundation, but not for the factors of maintenance and condition before overlay and environment.

<u>Joint Reflection Cracking Model</u>

A model for predicting joint reflection cracking was developed using data from 25 PCC pavements overlaid with one or more asphalt layers. Early studies of the data revealed that the variable FATAGE (a mechanistic variable that represents the total critical stresses to which the pavement has been subjected) was a very good predictor of the amount of pavement having joint reflection cracking present. After it was decided to use FATAGE, another variable had to be found that would improve the model and work well with it. The variable showing the best influence was the environmental variable of average daily temperature range. Interacting the average daily temperature range with the age of the pavement and then combining it with FATAGE gave the best results.

The linear regression model for joint reflection cracking was used as a starting point for nonlinear regression analysis. However, prediction models resulting from nonlinear regressions showed little, if any, improvement over the linear model in predicting joint reflection cracking. Also, sensitivity to the input variables became less favorable with the nonlinear models. Thus, the linear model was selected as the final prediction model for joint reflection cracking.

An evaluation of the model showed that, overall, the model does a good job in predicting the amount of pavement having joint reflection cracking present and is simple to use. The signs of both variables in the equation are positive. This is reasonable because, as the value of FATAGE increases, the amount of cracking should also increase. As the age of the pavement or the average daily temperature range increases, so will the amount of gradients that a pavement will experience. Increases in this number should be reflected in higher amounts of cracking, as shown by the positive coefficient in front of the daily temperature range variable. The equation would be plausible if all the variables that affect joint reflection cracking were included in the proper functional form. A sensitivity analysis showed that the model was adequate for the factors of traffic and environment, but not for the factors of pavement thickness or pavement condition before overlay.

DATA COLLECTION FOR MODEL VERIFICATION

New airfield pavement data were obtained from five of the 12 Air Force bases surveyed during FY 80. The new data were to be used for (1) verifying the models and (2) getting information on the progression of distress and on PCI trends over time.

The data included all historical data obtained from FY 80, plus:

1. Information on new pavement layers

2. New or updated traffic information

3. Major maintenance efforts

4. Current PCI and distress surveys.

The five Air Force bases were selected as being representative of the 12 bases surveyed during FY 80. New data were obtained for similar pavement types, range of climatic variables, and traffic. Data were collected for 101 features and divided into pavement types. Surveys were performed on runways, taxiways, and aprons, with most sections located in taxiways.

Some inconsistencies were found between the FY 80 and new data; however, in most cases, the data seemed reasonable. The new data were obtained from the same source used in FY 80.

All data were checked carefully to correct errors and to locate missing information. Means, frequencies, and other statistics were obtained to further verify the reasonableness of the data. The average life of an asphalt surface was also compared, using the old and new data.

MODEL VERIFICATION

The main purpose of collecting new data from the pavement features surveyed in FY 80 was to verify the models' ability to predict pavement performance. The new data were not used to develop models.

The input variables used to develop the prediction models were computed for the new data and input into the models to obtain the predicted value of the dependent variable. Ideally, all predicted values would equal the actual values. Verification of the models showed that the PCI prediction models are satisfactory. The reflection cracking model also provided reasonable prediction for the eight pavement features that had reflection cracking.

However, verification of the corner break model showed that it was not satisfactory. One of the reasons for this could be the range of corner breaking provided by the data used to develop the model (mostly 0 to 3 percent).

LOCALIZED MODELING CONCEPT

During the models' development and verification phase, it became apparent that as more data from different bases were added to the data bank, the prediction statistics became less and less conclusive, and reasonable models became harder to achieve. Better models were achieved by developing separate models for each Air Force base (localized data). This can be explained by the fact that some of the difficult variables to quantify, such as climate, have been eliminated by working with data from one locality. It was therefore recommended that this concept be further developed and incorporated in the PAVER system, rather than replacing the models presented in Volume VII with those developed in Volume IX.

SECTION VIII

ADOPTION OF PAVER

The use of the pavement maintenance management system (PAVER) also extends to roads and streets. The system was designed for use by military installations, cities, and counties. PAVER provides the engineer with a practical decisionmaking procedure for identifying cost-effective M&R on roads, streets, and airfields. The system provides the user with report generation capability for critical information, which allows objective input to the decision making process.

PAVER provides the user with many important capabilities. These include data storage and retrieval, pavement network definition, pavement condition rating, project prioritization, inspection scheduling, determination of present and future network conditions, determination of M&R needs, performance of economic analysis, and budget planning.

DATA STORAGE AND RETRIEVAL

The PAVER data base is a custom-designed data structure defined in a commercially available computer data base manager called System 2000. The data structure consists of 12 linked data groups. Thus, the user can retrieve information based on its connection to other data in the data base. The data can be stored and retrieved through special interactive interface programs, so the user has immediate access to the data base.

PAVEMENT NETWORK DEFINITION

A pavement network consists of all surface areas that provide accessways for the ground or air traffic. This network must be divided and identified in order to use the data base. Networks are divided into branches, sections, and sample units. The data base then provides information on the pavement network through reports such as "Lists" or "Inventory."

PAVEMENT CONDITION RATING

A key component of any pavement management system is a condition rating procedure. The PAVER system uses the PCI, which has been divided into seven condition categories, ranging from "excellent" to "failed." These categories are useful for developing maintenance policies and guidelines. The PAVER data base uses reports such as "PCI," "Inspect," and "Sample" to provide PCI information.

PROJECT PRIORITIZATION

Project prioritization is an immediate payoff of pavement network definition and pavement condition rating. The "PCI" report can be used for this purpose. It lists pavement sections in an increasing order of PCI. The report information can be sorted, based on pavement surface type, pavement rank, traffic type and volume, PCI range, or a combination of factors.

INSPECTION SCHEDULING

The inspection schedule report has been developed to maintain current condition data with an efficient inspection level. The report produces a plot and list of the pavement sections to be surveyed for the next 6 years for any type of branch use and surface type. The schedule is based on two criteria. One is the minimum PCI a given pavement type is allowed to reach, and the second is the rate of deterioration. The user inputs the minimum PCI values and the years allowed between inspections for various deterioration rates. The PCI for the selected sections is then predicted by a straight-line extrapolation, based on the maximum slope from either the last inspection or construction/overlay date. Sections reaching the minimum PCI within 6 years or reaching the time limit based on the rate of deterioration, will be selected for inspection in the appropriate years.

DETERMINATION OF PRESENT AND FUTURE NETWORK CONDITION

An overall frequency-of-condition report ("FREQ") has been developed to help plan future M&R and to inform management of the network condition. The report shows an estimated frequency of condition, based on the PCI scale, for the year requested. The pavement section included in the report can be selected based on branch use, pavement rank, and surface type.

DETERMINATION OF M&R NEEDS

A decision process has been devised for determining the M&R needs of a pavement section. A first-level decision can be based on the "PCI" value, type of distress, and deterioration rate. PAVER provides reports such as "PCI" and "Condition History" to help the user make the first decision. The PCI report is an ordered listing of sections ranked by PCI. The Condition History report can be used to determine the rate of deterioration; the report plots the PCI over time for a given section. The plot shows the PCI at each inspection date and linearly extrapolates a point 5 years beyond the last inspection date. If a pavement section does not need further analysis, routine maintenance can be continued. If a section requires further analysis, an evaluation summary is completed for the section.

PERFORMANCE OF ECONOMIC ANALYSIS

Several repair or construction alternatives may be considered feasible for any given pavement section. To help select the appropriate alternative, an economic analysis program has been developed. The program allows the user to input initial costs, periodic maintenance costs, and separate future maintenance costs. Output is the initial cost, present value, equivalent uniform annual cost, and equivalent uniform annual cost per square yard. The program allows the user to vary interest rates, inflation rates, repair costs, and timing. Information provided is in the form of projected cost analyses and equivalent uniform annual cost per square yard.

BUDGET PLANNING

A Budget Planning report ("BUDPLAN") was developed to provide an estimate of the rehabilitation dollars required over a 10-year period for a given level of condition. The report is based on the user's input of minimum PCI levels for various branch uses and pavement rank. The user also inputs unit repair costs based on pavement surface type and the PCI scale. Thus, the increased cost of different rehabilitation can be anticipated. The program predicts, for each pavement section, the year in which the minimum PCI is reached and calculates the cost of repair.

USE OF PAVER

The Air Force is currently evaluating PAVER at six bases. Based on its analysis of its performance, the Air Force will decide whether to implement PAVER on a worldwide basis.

SECTION IX

CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the work performed by USA-CERL for the Air Force from 1974 through 1983 for the development of an airfield pavement maintenance management system. All procedures developed during this effort have been computerized and included in the PAVER pavement management system, which also includes a management system for roads. The PCI prediction models in PAVER were those presented in Volume VII. Even though the PCI prediction models developed in Volume IX are more accurate, it was decided that the best prediction approach should be through local models for each base, rather than one model for all bases. An effort to develop this modeling concept, called "localized dynamic modeling," is currently underway through funding from the U.S. Army.

The PCI procedures developed as part of this program (Volume V), as well as the M&R guidelines (Volume VI), have been adopted by the U.S. Air Force through AFR 93-5, and through the Major Command and U.S. Air Force Headquarters requirements for approval of projects. It is recommended that the PAVER system be implemented by individual Air Force bases to allow use of the computerized procedures presented in Volume VIII. The PAVER system will provide the needed data bank for use of the localized modeling techniques when development is completed (probably in FY 85-86).

Recommended future research and development include the enhancement of the various PAVER models and outputs, including condition prediction and optimization. Consideration should also be given to interfacing the existing Air Force pavement design and load-carrying programs with the PAVER system.

BIBLIOGRAPHY

Airfield Pavement Evaluation Program, Air Force Regulation 93-5 (Department of the Air Force, 18 May 1981).

Shahin, M. Y., M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume I: Airfield Pavement Condition Rating, AFCEC-TR-76-27 (Air Force Civil Engineering Center, November 1976).

Shahin, M. Y., M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume II: Airfield Pavement Distress Identification Manual, AFCEC-TR-26-27 (Air Force Civil Engineering Center, November 1976).

Shahin, M. Y., M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume III: Maintenance and Repair Guidelines for Airfield Pavements, CEEDO-TR-77-44 (Civil and Environmental Engineering Development Office, September 1977).

Shahin, M. Y., M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume IV: Appendices A Through I, Maintenance and Repair Guidelines for Airfield Pavements, CEEDO-TR-77-44 (Civil and Environmental Engineering Development Office, September 1977).

Shahin, M. Y., M. I. Darter, and S. D. Kohn, Development of a Pavement Maintenance Management System, Volume V: Proposed Revision of Chapter 3, AFR 93-5, CEEDO-TR-77-44 (Civil and Environmental Engineering Development Office, October 1977).

Shahin, M. Y., Development of a Pavement Maintenance Management System, Volume VI: M&R Guidelines--Validation and Field Applications, ESL-TR-79-18 (Engineering and Services Laboratory, December 1979).

Shahin, M. Y., M. I. Darter, and T. T. Chen, Development of a Pavement Maintenance Management System, Volume VII: Maintenance and Repair Consequence Models and Management Information Requirements, ESL-TR-79-18 (Engineering and Services Laboratory, December 1979).

Shahin, M. Y., S. D. Kohn, R. L. Lytton, and E. Japel, Development of a Pavement Maintenance Management System, Volume VIII: Development of an Airfield Pavement Maintenance and Repair Consequence System, ESL-TR-81-19 (Engineering and Services Laboratory, April 1981).

Shahin, M. Y., Development of a Pavement Maintenance Management System, Volume IX: Development of Airfield Pavement Performance Prediction Models, ESL-TR-83-45 (Engineering and Services Laboratory, May 1984).