working PMS that satisfies agency needs and expectations.

REFERENCES

1. W.N. Carey, Jr. and P.E. Irick. The Pavement Serviceability-Performance Concept. HRB, Bull. 250, 1960, pp. 40-58.
2. J.A. Epps et al. Roadway Maintenance Evaluation: User's Manual. Texas Transportation Institute, Texas A&M Univ., College Station, Research Rept. 151-2, Sept. 1974.
3. F.N. Finn, R. Kulkarni, and K. Nair. Materials Research and Development, Inc. Pavement Management System Feasibility Study. Washington Highway Commission, Department of Highways, Olympia, Final Rept., Aug. 1974.
4. F.N. Finn. Management System for Pavement Maintenance. ASCE Transportation Journal, Vol. 105, No. TE4, July 1979.
5. C. Bartell and K. Kampe; California Department of Transportation. Development of the California Pavement Management System: Vol. 1--System Description. FHWA, Final Rept. FHWA-CA-HM-7139-78-03, Oct. 1978.

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

# Implementation of Idaho's Pavement Management System

M.A. KARAN, K. LONGENECKER, A. STANLEY, AND RALPH HAAS

**The Idaho Department of Transportation (ITD) decided in 1979 to begin implementation of a comprehensive pavement management system, initially for their Interstate network and then for their state highway network. Two major phases have been involved in this implementation: (a) inventory of the Interstate network, documentation of the pavement performance management information system (PPMIS) program that was obtained from Utah, modifications and improvements to PPMIS, and implementation of PPMIS to the Interstate mileage and (b) further modification of the PPMIS program based on the findings of phase 1, expansion of the system to better suit ITD's needs, and verification of the new version of the PPMIS programs by using inventory data gathered in phase 1. The two phases of the project are described, including the original PPMIS program, modifications and extensions made, field inventory procedures used to collect data, implementation procedures employed, and assessment of the results. Phase 1 indicated that the PPMIS was a technically sound tool that could form the basis for Idaho's pavement management system. However, further improvements and modifications were necessary to fine-tune the system for Idaho conditions. These modifications and extensions were accomplished in phase 2. The Idaho version of PPMIS has been installed on ITD's computer facilities and is now operational. ITD personnel have used it effectively in making decisions regarding the management of the pavement network in the state.**

Idaho's highway network includes about 612 miles of Interstate highways plus about 5,000 miles of paved or oiled state highways. Considering the size and population of the state, this represents a substantial investment and presents a major management challenge, especially when funds are scarce and the demand is increasing, as has been the case in the last decade or so.

Under the circumstances that currently exist the limited rehabilitation and maintenance dollars have to be spent in such a way as to ensure the maximum return to the state and to the taxpayers. The concept of pavement management provides an effective tool to achieve this objective. The Idaho Transportation Department (ITD) thought that the benefits of implementing a pavement management system in the state were worthwhile and thus began to plan actively toward their goal in 1977-1978.

The first step was a review of what was available. Utah's Pavement Performance Management Information System (PPMIS) was chosen because it offered a sound basis on which to develop and implement a system for Idaho. In addition to the features of PPMIS, because Idaho and Utah were similar in many respects, the regional and technical aspects of PPMIS were thought to be reasonably applicable to Idaho conditions.

The PPMIS program was acquired from Utah in 1978 and made operational on the ITD computer. Several difficulties arose, however, in applying the program. First, PPMIS was designed for Utah conditions and some of these are not directly transferable to Idaho without further calibration. Second, some of the models either needed improvement or modification to apply to Idaho. For these and several other reasons, the initial results of PPMIS were questionable from the standpoints of practicality and reasonableness.

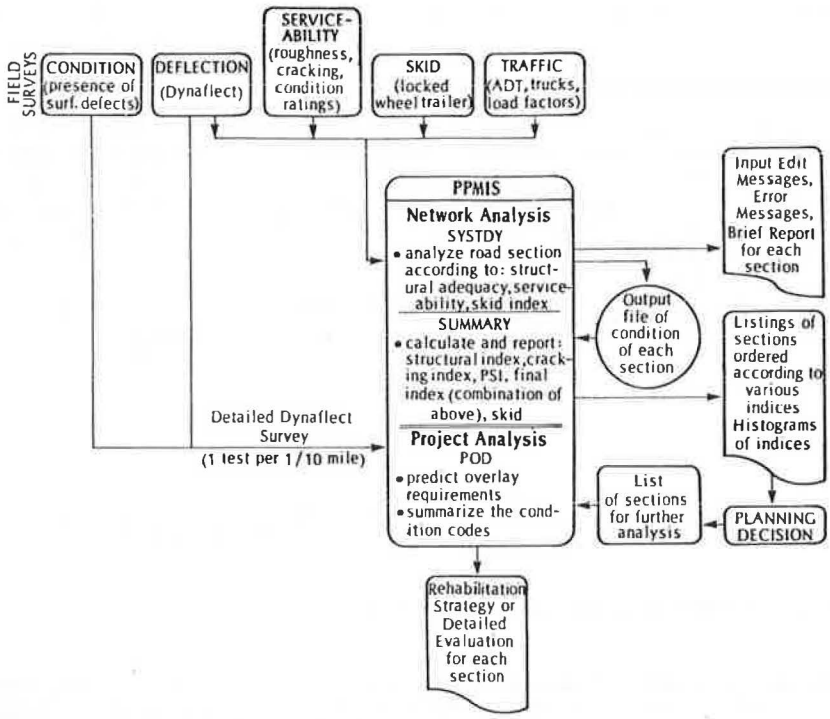
In 1979 ITD decided to accelerate its pavement management system development and implementation. The project was split into two phases because of fiscal planning considerations, and the first contract was awarded in August 1979 and completed in June 1980. The basic terms of reference for phase 1 were to conduct field inventory data collection on the Interstate mileage, document the PPMIS program, carry out certain modifications and improvements to PPMIS, and initiate the implementation of PPMIS to the Interstate mileage.

The second contract was initiated in October 1980 and completed in June 1981. In general, the terms of reference for phase 2 were to further modify the PPMIS program based on the findings of phase 1, expand the system to better suit ITD's needs, verify the resulting new version of the PPMIS programs by using inventory data gathered in phase 1, install the system on the ITD computer in Boise, and provide the required instructions.

The purpose of the paper is to describe the two phases of the overall project, specifically the following:

1. The original PPMIS program and procedures used for documentation and evaluation,
2. The modifications and extensions made to the original PPMIS program to suit ITD's needs and requirements,
3. The field inventory procedures used to collect data on the Interstate mileage,
4. The trial implementation procedures employed and assessment techniques used, and
5. The evaluation of the results and benefits derived from the system.

Figure 1. Overview of PPMIS program structure.




## PHASE 1: DOCUMENTATION, MODIFICATION, AND APPLICATION OF INITIAL IDAHO PPMIS

The initial version of the Idaho PPMIS comprises three main computer programs, SYSTDY, SUMMARY, and POD. In terms of the general philosophy of pavement management these programs cover the two basic levels that should be included in a pavement management system--the network and project levels.

The general structure of PPMIS is presented in Figure 1. Programs SYSTDY and SUMMARY are grouped under network analysis (i.e., the network level of management) and program POD is under project analysis (i.e., the project level).

Analysis at the network level begins with program SYSTDY, which edits and processes the various types of information gathered in field surveys of the pavement network. SYSTDY transforms and organizes the field data into a highly summarized format for each pavement section in the network and also produces a brief printed report for each section.

The summarized data are subsequently used as input to program SUMMARY. This program transforms the summarized measurements into indices [i.e., structural adequacy, present serviceability (PSI), and distress indices]. These various indices are combined into a final, overall index value for each section. The sections analyzed are listed in ascending order of the various index parameters (including skid numbers) considered, and histograms are produced for each list.

The final report is a ranked list of sections in the network that can be used for programming improvements. In addition to the final index list, histograms are also produced of summaries for the various parameters processed in this program. Note that, although these final rankings can be used for priorities, an economic analysis of alternative improvement types and timings for the various sections might well result in a substantially different priority list. Consequently, the ranked list may be viewed more as the first step toward an eventual priority ordering based on economic optimality in that it represents a list of needs.

From the ranked list produced by program SUMMARY, a number of sections can be identified for more detailed project analysis. More extensive field testing can then be performed on these sections. This information is subsequently used by program POD in a more comprehensive analysis to provide a detailed evaluation and, if desired, a recommended rehabilitation strategy for each section. Each one of these three main programs (SYSTDY, SUMMARY, and POD) contains a series of subroutines (1). Sample outputs are subsequently provided in this paper.

### Modifications to Initial Idaho PPMIS

The initial version of the Idaho PPMIS was tested by ITD personnel on portions of the Idaho Interstate Highway System and, as a result, the need for modifications was recognized first by them. Hence, the primary motivation for the modifications came from the need to adapt the initial PPMIS to conditions in Idaho.

During the subsequent documentation of this initial system in phase 1 a number of inconsistencies, errors, and shortcomings were found. These resulted in numerous modifications and improvements to the system. In some cases modifications were made to improve the operation of the program or to clarify the results presented. The objectives were to make the overall system as efficient as possible and to make the output as informative as possible.

The modifications made to the initial Idaho PPMIS can be classified into the following basic categories:

1. Corrections,
2. Technological adaptations,
3. Regional adaptations, and
4. Improvements.

Corrections include changes to the program structure because of illogical operation sequencing, extraneous or extra required steps in the logic, erroneous or inaccurate Fortran coding, and unreasonable parameter values. Technological adapta-

tions include all changes to input format, variable definition, program structure, and mathematical models made necessary by the use of different equipment for the field inventory. Regional adaptations include the respecifications of limits, constraints, parameter values, and the methods of calculating certain parameters to reflect Idaho conditions and practices more accurately. Improvements are primarily in terms of the changes to print routines to produce reports that are easier to follow and less open to misinterpretation.

These modifications (1) are listed in Table 1 under the categories for each main program in PPMIS. The modifications conducted in phase 1 of the project resulted in the modified Idaho PPMIS that was then applied to the flexible pavements of the state's Interstate network.

## Field Inventory Measurements

The modified Idaho PPMIS program requires the following four basic types of inventory information:

1. Structural capacity,
2. Surface condition,
3. Roughness, and
4. Skid resistance.

Structural capacity, which is based on deflection measurements taken on the surface of the pavement structure, is used in PPMIS to incorporate engineering input into the analysis. Surface condition information is used indirectly by the analyst or engineer to determine (a) where an accelerated loss of serviceability will most likely occur and (b) maintenance needs. Roughness information, which is the basis for determining the serviceability level of a pavement, is used in PPMIS to take into account the road user's response in addition to engineering measures such as structural capacity. Skid resistance information is used in PPMIS to identify pavement sections that have the potential for skid problems. The information is not analyzed in PPMIS. It is simply listed as supplementary information should criteria for minimum skid resistance be used.

In phase 1 the field measurements performed in collecting inventory information on the 612 miles of Interstate highway network included the following:

1. Section identification,
2. Deflection measurements,
3. Roughness measurements,
4. Surface condition survey, and
5. Skid measurements.

## Section Identification

In the first task of the field work 612 miles of Interstate highways were broken into sections by ITD personnel. The existing milepost and coded segment (MACS) (2) system, past experience, contract lengths, traffic volumes, pavement type, age and thickness, and geometric characteristics were taken into consideration in the section identification process.

Sections were identified (by using the existing milepost system) separately in each direction of travel on four-lane divided Interstate highways. No directional split was considered on two-lane undivided portions of the Interstate system. In light of these considerations and through extensive field studies 376 sections were identified on the 612 miles of the Interstate highway system in the state.

## Deflection Survey

Three Dynaflect deflection tests per mile, with a minimum of three tests per section, was the initial sampling frequency proposed, as opposed to one test per mile required by the original Utah PPMIS. The specific requirements of the modified Idaho PPMIS, size of the network, availability of equipment, personnel, time limitations, and statistical validity considerations were taken into account in designing this inventory scheme.

This sampling frequency was initially implemented for the Interstate highways in district 3. Statistical analyses were conducted after one week of testing to determine the significance of sampling at three tests per mile with a spacing of 0.1 mile between tests. The third measurement of the sampling frequency of three tests per mile did not make a significant contribution to the mean deflection of the section. Statistical tests conducted for different section lengths resulted in the same conclusion.

The short sections that have lengths of less than a mile were exceptions to this conclusion. Three tests were necessary for these sections as required by the original Utah PPMIS. Therefore, the third test was eliminated and the remainder of the Interstate highway mileage in the state was surveyed by taking two tests per mile with a minimum of three tests per section.

Two Dynaflect units were employed in the survey. Measurements of rut depth and air and pavement temperature were also taken during the Dynaflect survey. A Dynaflect correlation study was also conducted as a part of phase 1 deflection inventory program of Interstate highways in Idaho to determine

**Table 1. Modifications to initial Idaho PPMIS.**

| Modification | Program SYSTDY | Program SUMMARY | Program POD |
|---|---|---|---|
| Corrections | Lane distribution factors, dynaflect conversion, order of calculations in structural analysis, adjustment of design period for environment, calculation of remaining years of structural adequacy, adjustment of roadmeter readings, calculation of total and average cracking plus patching, calculation of remaining years of acceptable serviceability, speed correction of skid indices | Calculation of cracking index | Dynaflect device conversion, calculation of annual traffic load, calculation of overlay thicknesses, testing for outliers |
| Technological adaptations | Serviceability data input, decimal conversion of serviceability input data, check for valid measurement device, conversion parameters for roadmeter data, conversion of roadmeter data, calculation of PSI | None | None |
| Regional adaptions | Minimum traffic growth rate limit, load equivalency factors | Calibration of cracking index model, calculation of final index, adjustments to final index | None |
| Improvements | Dynaflect readings and summary, serviceability summary, skidmeter summary | Skid index histogram | None |

the consistency of the Dynaflect units employed in the survey. No significant difference was found between the Dynaflect units when the average deflections for sections (both flexible and concrete) were considered. Hence, no conversion was necessary for the raw data because PPMIS used average values for the sections. Details of the Dynaflect correlation study can be found elsewhere (3).

## Roughness and Surface Condition Surveys

The automatic road analyzer (ARAN) unit (4-6) was employed to measure pavement roughness and to conduct a condition survey on the Interstate highway network in Idaho. The ARAN unit, which is housed in a van, measures roughness by use of an accelerometer mounted on the rear-axle housing of the vehicle. It can measure roughness (among many other pavement parameters) at 10-, 20-, 50-, and 100-m intervals at speeds up to 50 mph. In this project, however, roughness on the Interstate highway sections was measured on the traveling lane, at 50-m intervals and 30 mph operating speeds.

The condition survey that was conducted concurrently with the roughness survey was the main reason for using a relatively low speed. Roughness levels were measured and recorded automatically on a magnetic tape (in digital form) at 50-m intervals. The condition survey was conducted by a specially trained rater who was seated in the right front seat of the unit. The rater entered special codes (which were developed specifically for Idaho conditions and PPMIS program) into the system for the various distress parameters observed while traveling over the pavement by pressing the appropriate sequence of buttons on a hand-held keyboard.

A present serviceability index (PSI)-roughness correlation study was also conducted as a part of the phase 1 roughness survey program. A wide range of rural road sections (30 flexible and 12 rigid) in district 3 were selected for analysis and two, four-member panels of representative road users in the state were formed and trained in rating pavement serviceability.

The rating procedures used and extensive statistical analyses conducted, which are described in detail elsewhere (7), resulted in a reasonably good model for flexible pavements for predicting PSIs directly from ARAN roughness measurements. Although the model was also reasonable for rigid pavements, recommendations were made for further study in this area.

## Skid Measurements

Skid measurements on the Interstate highway mileage were taken by ITD personnel by using their locked-wheel skid trailer. One test per mile with a minimum of three tests per section was taken on the traveling lane, at an operating speed of 40 mph. Test location, friction force, and air and pavement temperatures were recorded manually on special forms that were then used to determine and adjust the skid numbers to be used in PPMIS.

## Application and Evaluation of Modified Idaho PPMIS

In order to test the reasonableness of the modified Idaho PPMIS the field inventory data collected on the Interstate system were used as input for a number of runs of the modified Idaho PPMIS program. The purpose of this application was to provide a basis for assessing the reasonableness of the modified Idaho PPMIS for conditions in Idaho.

A large-scale application was thought to be more meaningful in that it would enable the project team to test the system over a large sample size that covers a wide range of conditions that exist in Idaho. The pavement sections considered in this large-scale application were located in five out of the six ITD districts in the state.

Programs SYSTDY and SUMMARY were run for all the flexible pavement sections of the Interstate highways and the results were evaluated in the office. Next, extensive field inspections were performed with ITD officials for verification purposes. This was followed by meetings with the district staff who were most familiar with the pavement sections in their jurisdictions.

Similar to network analysis programs (i.e., SYSTDY and SUMMARY), project analysis program (POD) was run to analyze the detailed deflection and surface condition data collected on two sections in district 2. The results were then evaluated by the project team and ITD personnel who were most familiar with these projects. The results indicated that the PPMIS was a technically sound tool that could form the basis for Idaho's pavement management system; however, further improvements and modifications were necessary to fine-tune the system for Idaho conditions.

Phase 1 of the project then concluded with a number of recommendations for the calibration, improvement, extension, and further implementation of the system. These recommendations, which have been described in detail elsewhere (1), are summarized below.

Recommendations for network management are as follows:

1. Identify section (homogenity, length);
2. Determine network improvement needs;
3. Incorporate economic analysis;
4. Optimize network improvement sections, strategies, and timing; and
5. Conduct budget-level analysis and financial planning.

Recommendations for pavement behavior models are as follows:

1. Estimate structural condition,
2. Predict structural life,
3. Estimate present serviceability (PSI),
4. Estimate acceptable serviceability life,
5. Calculate cracking index, and
6. Conduct rigid pavement analysis.

Recommendations for program operation, structure, and logic are as follows:

1. Input structure,
2. Program structure and logic, and
3. Present output.

Recommendations for field inventory procedures are as follows:

1. Conduct deflection surveys,
2. Conduct roughness measurements,
3. Conduct condition surveys,
4. Conduct geometric surveys, and
5. Conduct skid surveys.

Recommendations for implementation and operation of the system are as follows:

1. Implement PPMIS for the state highway system,
2. Detail management responsibilities, and
3. Update inventory.

## PHASE 2: FURTHER MODIFICATION AND EXTENSION OF MODIFIED IDAHO PPMIS

The main objective of phase 2 of the project was to implement phase 1 recommendations to make PPMIS more compatible with the conditions that exist in Idaho. Specifically, the objectives were as follows:

1. Implement phase 1 recommendations in terms of modifications to the existing PPMIS to calibrate and adjust models for Idaho conditions,
2. Expand PPMIS's capabilities to analyze rigid pavements and to include graphical presentations,
3. Correlate ITD's new Cox roadmeter with present serviceability rating (PSR) for both flexible and rigid pavements,
4. Apply new PPMIS programs to phase 1 field inventory data and assess reasonableness of new programs,
5. Install and make operational new PPMIS programs on ITD computing facility and provide reports and manuals, and
6. Conduct training course for ITD personnel in the operation of the system.

### Developments for PPMIS Modification

The following developments, completed in phase 2 of the project, have either been implemented as modifications to PPMIS or will be implemented at a later date as determined by ITD.

#### Flexible Pavement Structural Condition Models

In phase 1 the models developed in Utah for evaluating the structural condition of flexible pavements were reviewed and found to be questionable for conditions in Idaho. Consequently, a more general model was developed by using deflections measured on the Idaho Interstate highway system in phase 1 and incorporating the spreadability and deflection basin area. The new models produced more reasonable results than did the Utah models.

#### Flexible Pavement Structural Life Models

Experience gained in phase 1 was used to develop a new environmental adjustment model for analyzing flexible pavements in Idaho. The models that were in PPMIS had been developed specifically for conditions in Utah and were found to be questionable for conditions in Idaho.

#### Structural Index Model

A new model was developed for calculating the structural index in program SUMMARY to make it compatible with the evaluation indices.

#### Serviceability Life Models

The original regression equations developed in Utah for predicting the remaining number of years of acceptable serviceability were assessed as to their applicability to conditions in Idaho and were found to be reasonable.

#### Flexible Pavement Cracking Index Model

A new cracking index model was developed to replace the original (modified for Idaho) model in PPMIS. This model was based on ITD's new crack rating system.

#### PSI-Cox Roadmeter Roughness Correlation

The correlation developed in phase 1 (7) was replaced with two new separate models for flexible and rigid pavements. Meyer and Karan (8) provide details of this correlation study.

#### Traffic Load Calculations

A new table of load equivalency factors was incorporated into the PPMIS program to facilitate updating as new information became available. After subsequent tests and several modifications to the calculation procedures the results were found to be questionable and, thus, the concept of using truck factors was applied as a temporary measure.

#### Input Structure

The input structure of PPMIS was changed significantly to accommodate certain modifications and extensions such as analysis of portland cement concrete (PCC) pavements. Users manuals (7,8) provide detailed descriptions of these changes.

#### Program Structure

Modifications in the structure of the PPMIS programs were necessary to facilitate the incorporation of several new analysis models such as those for PCC pavements, adjustments, and extensions. Some programs were rewritten, and the sequence of operations on some other programs was changed to increase efficiency.

#### Presentation of Output

Significant changes were made to PPMIS outputs to accommodate the modifications and extensions made to the analysis techniques (i.e., PCC pavements). One of the major changes is that PPMIS no longer requires all four of the major types of field data (i.e., deflection, roughness, surface condition, and skid) to produce a report. Figure 2, for example, shows SYSTDY output for a section where deflection and skid data are not present. Figure 3 is another example with all data types present. This feature of the program was extended to the SUMMARY program, as shown in Figures 4 and 5. The graphical presentation shown in Figures 4 and 5 was added to the program in addition to the tabular outputs that were available in the original PPMIS. Figure 6 shows sample tabular output of SUMMARY program.

As with the SYSTDY and SUMMARY programs, the output of POD was reconstructed to produce a more meaningful report. Tabular presentations were changed to facilitate ease of use. Summary tables were also added. A major addition to the POD output is the capability to report the tabulated information in a pictorial format. Figure 7 presents a tabular POD output and Figure 8 presents a graphical POD output.

### Developments for Expansion of PPMIS Capabilities

The following developments were completed in phase 2 of the project and have either been incorporated into the PPMIS program or may be considered for implementation at a later data as determined by ITD.

#### Rigid Pavement Structural Analysis

A model based on Dynaflect deflection for evaluating the structural life and overlay requirements of rigid pavements was developed and calibrated for conditions in Idaho. The model covers only asphalt overlays of rigid pavements. A model for designing concrete overlays for rigid pavements was not included in PPMIS because of the funding limitations. The model selected for implementation in PPMIS was

**Figure 2. Sample SYSTDY output for selected data types.**

```
IDAHO PPMIS (2)  MACS: 01570B N 111.859  DIST: 6  COUNTY: BONNEVILLE      19  CITY:                    0 FAI-15     7/ 1/81
IDAHO ROUTE:  15  BINGHAM CO LINE            MILEPOST: 111.859     IDAHO FALLS SUL          MILEPOST: 118.000  LENGTH:   6.17
MATERIAL: PLANT MIX SEAL COAT  BIT. SF. (PMSC)  MAINTENANCE SHED:        WIDTH: 12.00
YEARLY INCREASE IN 18KIP LOADS:    4.0%     PRESENT 18KIP LOADS:        0.23569E+06     T. S. I. 2.5

                                   NO  DYNAFLECT  READINGS  ARE  RECORDED

      ***CONDITION SUMMARY***                    ***SERVICEABILITY SUMMARY***
AVERAGE CONDITIONS                     DATE   9/26/79
SURFACE WEAR  5.0  POPOUTS     N/A     TEST      SERV LIFE    100 +
WEATHERING    5.0  UNIFORMITY  N/A      NO.  PSI   REMAIN   %     I                          71      NO  SKID  DATA  ARE
RUT DEPTH     0.0                        1   3.9      9        80 +                          **
                                         2   4.1     11     O     I                          **
AVG. CRACKING AND PATCHING               3   4.2     14     F  60 +                          **
 ( PER 1000. SQ. FT.)                    4   4.2     14           I                          **
TRANSVERSE      (FT.)     4.             5   4.2     13     T  40 +                          **
LONGITUDINAL    (FT.)     3.             6   4.0     10     E     I                    14 14 **
MAP          (SQ.FT.)     0.             7   4.3     14     S  20 +                    ** ** **
ALLIGATOR    (SQ.FT.)    N/A           MEAN  4.1   12.1     T     I                    ** ** **
PATCH-SKIN   (SQ.FT.)     0.            S.D.  0.1    2.1     S   0 +-+-+-+-+-+-+-+-+-+-+-+-+
PATCH-DEEP   (SQ.FT.)     0.                                      0 1 2 3 4 5 6 7 8 9 10 >10
AVG CONDITION OF TRANS,LONG CRACKS
OPENING        5.0   ABRASION  N/A                                REMAINING STRUCTURAL LIFE (YEARS)
MULTIPLICITY   5.0                                                BASED ON PSI
```

**Figure 3. Sample SYSTDY output for rigid pavement section.**

```
IDAHO-PPMIS (2)  MACS: 0907UA E   6.146  DIST: 1  COUNTY: KOOTENAI        55  CITY:                    0 FAI-90     7/ 1/81
IDAHO ROUTE:  90  POST FALLS ECL              MILEPOST:   6.146     COEUR D'ALENE WUL        MILEPOST:   9.739  LENGTH:   3.59
MATERIAL: CONCRETE    (CONC)                    MAINTENANCE SHED:        WIDTH: 12.00
YEARLY INCREASE IN 18KIP LOADS:    3.9%     PRESENT 18KIP LOADS:        0.43305E+06     T. S. I. 2.5

                                   ***DYNAFLECT READINGS AND SUMMARY***
 DATE   9/20/79  HR 11 MIN 51     TEMPERATURES: AIR  78.1 SURFACE   0.0 PAVEMENT   N/A
 WHEEL PATH  OSWP       LANE EB-1    LAST REVISION 092079
                                                                                  100 +
 TEST      SNSR  SNSR  SNSR  SNSR  SNSR   SCI  BCI   CORNER  OVER  REMAINING SERVICE  %     I
  NO.       1     2     3     4     5                SNSR 1  -LAY  LIFE (STRUCTURAL)     80 +
                                                                    18K LOADS YEARS    0     I
    1      0.33  0.28  0.25  0.20  0.15  0.05 0.05    N/A     N/A  3.002E+06    10    F  60 +            50
    2      0.28  0.25  0.23  0.18  0.15  0.03 0.03    N/A     N/A  3.002E+06    10          I            **
    3      0.39  0.35  0.31  0.26  0.21  0.04 0.05    N/A     N/A  1.832E+06     7    T  40 +            **
    4      0.41  0.37  0.34  0.28  0.22  0.04 0.06    N/A     N/A  1.690E+06     6    E     I12 12 12 12 **
    5      0.28  0.25  0.22  0.18  0.14  0.03 0.04    N/A     N/A  3.278E+06    10    S  20 +** ** ** ** **
    6      0.32  0.28  0.24  0.19  0.14  0.04 0.05    N/A     N/A  3.278E+06    10    T     I** ** ** ** **
    7      0.65  0.60  0.52  0.41  0.31  0.05 0.10    N/A     N/A  7.614E+05     3    S   0 +-+-+-+-+-+-+-+-+-+-+-+-+
    8      0.85  0.80  0.71  0.58  0.45  0.05 0.13    N/A     N/A  2.778E+05     1          0  2  4  6  8 10 12 14 16 18 20 >20

MEAN       0.44  0.40  0.35  0.29  0.22  0.04 0.06    N/A     N/A  2.140E+06   7.1            REMAINING STRUCTURAL LIFE (YEARS)
STD DEV.   0.20  0.20  0.17  0.14  0.11  0.01 0.03    N/A     N/A  1.180E+06   3.6
MEAN - SD  0.23  0.20  0.18  0.14  0.11  0.03 0.03    N/A     N/A  9.605E+05   3.6
MEAN + SD  0.64  0.60  0.53  0.43  0.33  0.05 0.10    N/A     N/A  3.320E+06  10.7
OUTLIERS ******************  0.58  0.45

      ***CONDITION SUMMARY***                    ***SERVICEABILITY SUMMARY***                  ***SKIDMETER SUMMARY***
AVERAGE CONDITIONS                     DATE   9/20/79                                        DATA IS SPEED-COMPENSATED
SURFACE WEAR  5.0  POPOUTS     N/A     TEST      SERV LIFE    100 +                           TEST NO.   SKID INDEX
WEATHERING    3.7  UNIFORMITY  N/A      NO.  PSI   REMAIN   %     I          75                 1          38
RUT DEPTH     0.0                        1   3.8      7        80 +          **                 2          39
                                         2   3.7      7     O     I          **                 3          38
AVG. CRACKING AND PATCHING               3   3.9      8     F  60 +          **                 4          38
 ( PER 1000. SQ. FT.)                    4   3.6      6           I          **                MEAN        38.3
TRANSVERSE      (FT.)    33.            MEAN  3.8    7.0     T  40 +       25 **                S.D.        0.5
LONGITUDINAL    (FT.)     0.            S.D.  0.1    0.8     E     I       ** **
MAP          (SQ.FT.)     0.                                 S  20 +       ** **
ALLIGATOR    (SQ.FT.)    N/A                                 T     I       ** **
PATCH-SKIN   (SQ.FT.)     0.                                 S   0 +-+-+-+-+-+-+-+-+-+-+-+-+
PATCH-DEEP   (SQ.FT.)     0.                                       0  2  4  6  8 10 12 14 16 18 20 >20
AVG CONDITION OF TRANS,LONG CRACKS
OPENING        5.0   ABRASION  N/A                                REMAINING STRUCTURAL LIFE (YEARS)
MULTIPLICITY   3.0                                                BASED ON PSI
```

**Figure 4. Sample summary sheet showing distribution of road miles by all evaluation indices.**

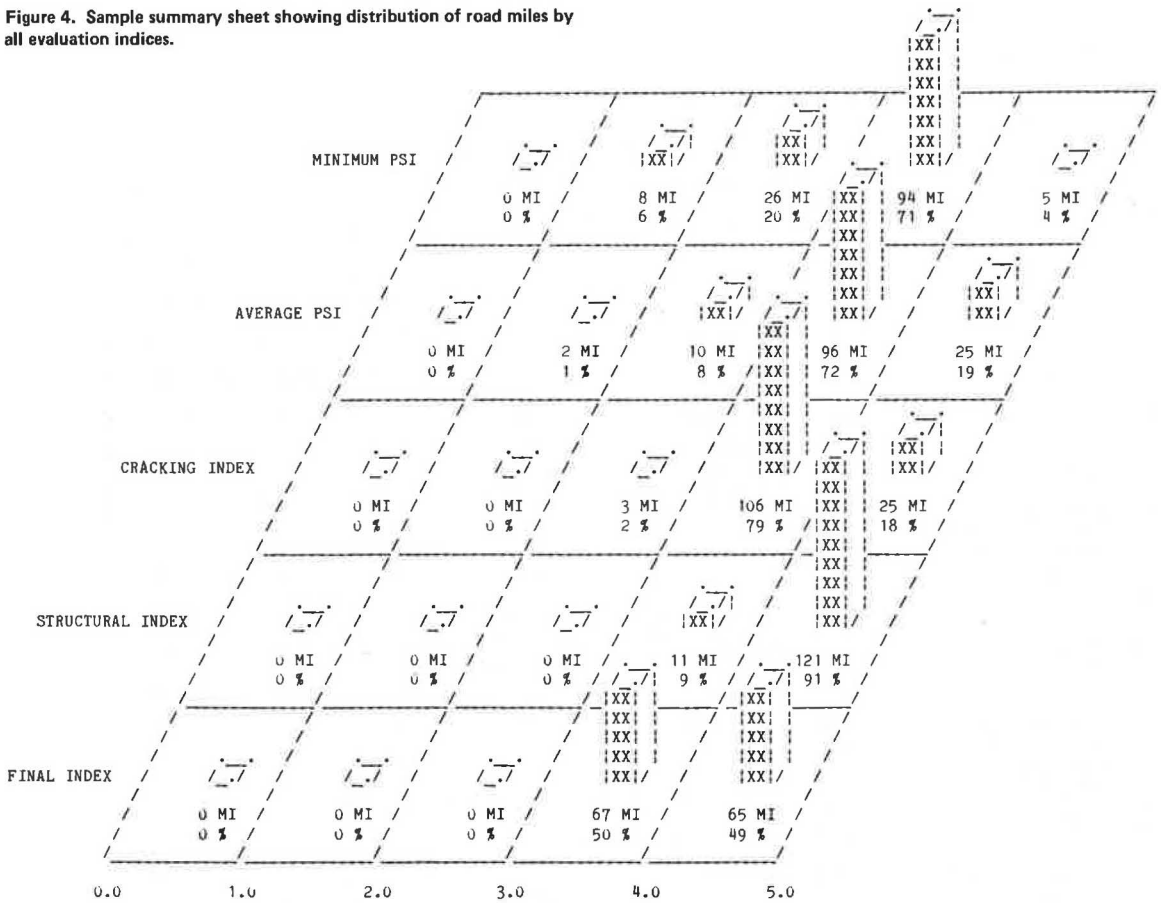



**Figure 5. Sample summary output showing distribution of road miles by evaluation indices when structural index is excluded.**

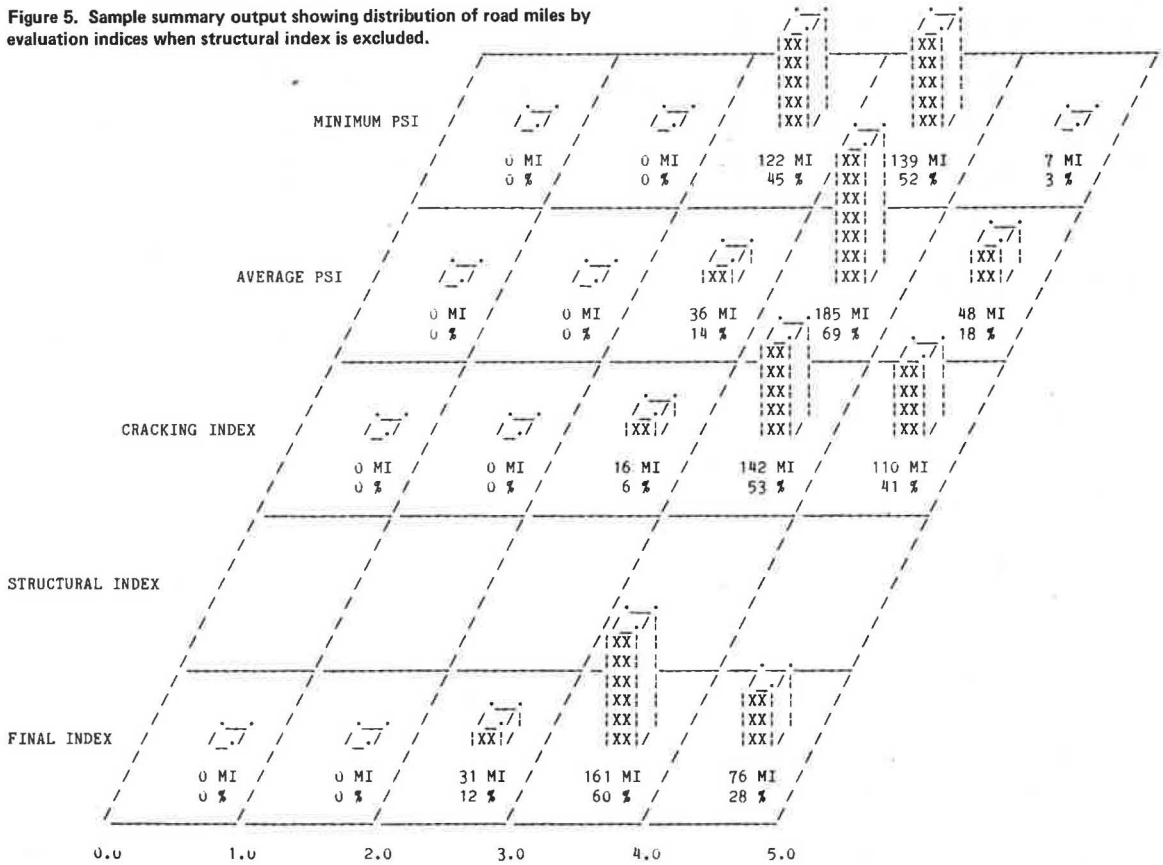


**Figure 6. Sample output from program summary.**

```
*-*-*-*-*-*-*-*-*-*-*-*-*
*                       *
*  FINAL SUMMARY TABLE  *
*                       *
*          OF           *
*                       *
*  PAVEMENT EVALUATION  *
*                       *
*         FOR           *
*                       *
*    DISTRICT NO. 4     *
*                       *
*-*-*-*-*-*-*-*-*-*-*-*-*
```

STRUCT=STRUCTURAL INDEX

CRACK=CRACKING INDEX

PSI=PSI INDEX

AVG FRIC=AVERAGE FRICTION INDEX

| | CNTY | ROAD SEGMENT CODE | LENGTH | BEGINNING TERMINI | START | ENDING TERMINI | END | FINAL INDEX | RANKING OF STRUCTURE,FRICTION CRACKING & PSI: STRUCT | CRACK | PSI | AVG FRIC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 53 | 08070D | 3.66 | SH 79 IC | 168.36 | J COOLEE CANAL | 164.70 | 3.0 | 2.5 | 3.1 | 3.2 | 31.0 |
| 2 | 31 | 08070D | 5.80 | MINIDOKA CO LINE | 216.04 | SALT LAKE IC | 221.84 | 3.0 | 4.5 | 2.5 | 2.3 | 34.0 |
| 3 | 31 | 08070D | 5.80 | SALT LAKE IC | 221.84 | MINIDOKA CO LINE | 216.04 | 3.1 | 4.5 | 3.1 | 2.1 | 31.0 |
| 4 | 53 | 08070D | 6.40 | NORTHSIDE CANAL | 194.14 | MINIDOKA CO LINE | 200.54 | 3.1 | 4.5 | 2.6 | 2.5 | 39.0 |
| 5 | 53 | 08070D | 6.40 | MINIDOKA CO LINE | 200.54 | NORTHSIDE CANAL | 194.14 | 3.1 | 4.5 | 2.6 | 2.5 | 37.0 |
| 6 | 67 | 08070D | 7.21 | JEROME CO LINE | 200.54 | SH 27 IC | 207.75 | 3.2 | 4.5 | 2.4 | 2.9 | 39.0 |
| 7 | 31 | 08070E | 6.28 | YALE RD IC | 228.12 | SALT LAKE IC | 221.84 | 3.3 | 4.5 | 2.9 | 2.6 | 33.0 |
| 8 | 53 | 08070D | 4.33 | US 93 IC | 172.69 | SH 79 IC | 168.36 | 3.3 | 1.5 | 4.0 | 4.2 | 39.0 |
| 9 | 67 | 08070D | 7.21 | SH 27 IC | 207.75 | JEROME CO LINE | 200.54 | 3.4 | 4.5 | 2.9 | 2.9 | 34.0 |
| 10 | 53 | 08070D | 6.11 | VALLEY ROAD | 188.03 | NORTHSIDE CANAL | 194.14 | 3.4 | 3.5 | 3.0 | 3.6 | 29.0 |
| 11 | 31 | 01560A | 2.26 | POWER COUNTY LINE | 17.58 | NEAR RAFT RIVER | 15.32 | 3.5 | 2.0 | 4.1 | 4.1 | 55.0 |
| 12 | 53 | 08070D | 3.95 | US 93 IC | 172.69 | DRAIN DITCH | 176.64 | 3.5 | 2.0 | 4.1 | 4.1 | 56.0 |
| 13 | 67 | 08070D | 8.29 | SH 27 IC | 207.75 | CASSIA CO LINE | 216.04 | 3.5 | 3.5 | 2.9 | 3.8 | 43.0 |
| 14 | 53 | 08070D | 4.33 | SH 79 IC | 168.36 | US 93 IC | 172.69 | 3.5 | 2.0 | 4.1 | 4.1 | 50.0 |
| 15 | 31 | 01560A | 2.26 | NEAR RAFT RIVER IC | 15.32 | POWER COUNTY LINE | 17.58 | 3.5 | 2.0 | 4.1 | 4.2 | 55.0 |
| 16 | 53 | 08070D | 6.11 | NORTHSIDE CANAL | 194.14 | VALLEY RD | 188.03 | 3.5 | 4.0 | 3.0 | 3.5 | 30.0 |
| 17 | 67 | 08070D | 8.29 | CASSIA CO LINE | 216.04 | SH 27 IC | 207.75 | 3.6 | 4.5 | 3.0 | 3.4 | 42.0 |
| 18 | 53 | 08070D | 5.06 | DRAIN DITCH | 176.64 | SH 50 IC | 181.70 | 3.6 | 3.5 | 3.6 | 3.8 | 49.0 |
| 19 | 31 | 08070E | 6.27 | SWEETZER ROAD | 253.91 | POWERLINE CROSSING | 247.64 | 3.7 | 4.5 | 2.8 | 3.6 | 44.0 |
| 20 | 53 | 08070D | 6.33 | VALLEY RD | 188.03 | SH 50 IC | 181.70 | 3.7 | 4.0 | 3.3 | 3.8 | 33.0 |
| 21 | 53 | 08070D | 3.38 | J COOLEE CANAL | 164.70 | GOODING CO LINE | 161.32 | 3.8 | 4.5 | 3.0 | 3.7 | 35.0 |
| 22 | 31 | 01560A | 8.00 | SALT LAKE IC | 0.00 | MILE POST 8 | 8.00 | 3.8 | 4.5 | 3.4 | 3.5 | 42.0 |
| 23 | 47 | 08070D | 5.29 | GOODING CO LINE | 161.32 | WENDELL WCL | 156.03 | 3.8 | 4.5 | 3.1 | 3.8 | 39.0 |
| 24 | 31 | 08070E | 6.28 | SALT LAKE IC | 221.84 | YALE RD IC | 228.12 | 3.8 | 4.5 | 3.3 | 3.7 | 42.0 |
| 25 | 47 | 08070D | 8.67 | EAST BLISS IC | 140.81 | BEG DIVIDED HWY | 149.48 | 3.9 | 4.0 | 4.1 | 3.6 | 27.0 |
| 26 | 31 | 08070E | 6.70 | POWERLINE CROSSING | 234.82 | YALE RD IC | 228.12 | 3.9 | 4.5 | 3.2 | 3.8 | 42.0 |
| 27 | 31 | 08070E | 7.11 | SWEETZER RD | 253.91 | ONEIDA CO LINE | 261.02 | 3.9 | 4.5 | 3.0 | 4.0 | 52.0 |
| 28 | 31 | 01560A | 7.32 | NEAR RAFT RIVER IC | 15.32 | MILE POST 8.000 | 8.00 | 3.9 | 4.5 | 3.4 | 3.8 | 39.0 |
| 29 | 31 | 08070E | 7.11 | ONEIDA COUNTY LINE | 261.02 | SWEETZER RD | 253.91 | 3.9 | 4.5 | 3.3 | 3.9 | 50.0 |
| 30 | 53 | 08070D | 6.33 | SH 50 IC | 181.70 | VALLEY ROAD | 188.03 | 3.9 | 4.0 | 3.7 | 4.0 | 31.0 |
| 31 | 53 | 08070D | 3.95 | DRAIN DITCH | 176.64 | US 93 IC | 172.69 | 4.0 | 3.5 | 4.1 | 4.2 | 52.0 |
| 32 | 31 | 08070E | 6.44 | POWERLINE CROSSING | 247.64 | HALFWAY BTW POWERLINES | 241.20 | 4.0 | 4.5 | 3.5 | 3.9 | 42.0 |
| 33 | 31 | 08070E | 6.70 | YALE RD IC | 228.12 | POWERLINE CROSSING | 234.82 | 4.0 | 4.5 | 3.5 | 4.0 | 36.0 |
| 34 | 53 | 08070D | 3.38 | GOODING CO LINE | 161.32 | J COOLEE CANAL | 164.70 | 4.0 | 4.5 | 3.7 | 3.9 | 40.0 |
| 35 | 31 | 01560A | 7.32 | MILE POST 8 | 8.00 | NEAR RAFT RIVER IC | 15.32 | 4.0 | 4.5 | 3.5 | 4.0 | 41.0 |
| 36 | 31 | 08070E | 6.27 | POWERLINE CROSSING | 247.64 | SWEITZER RD | 253.91 | 4.1 | 4.5 | 3.3 | 4.2 | 44.0 |
| 37 | 53 | 08070D | 3.66 | J COOLEE CANAL | 164.70 | SH 79 IC | 168.36 | 4.1 | 4.0 | 4.1 | 4.1 | 52.0 |

**Figure 7. Sample page of POD output for rigid pavement section of I-90.**

SECTION : I - 90

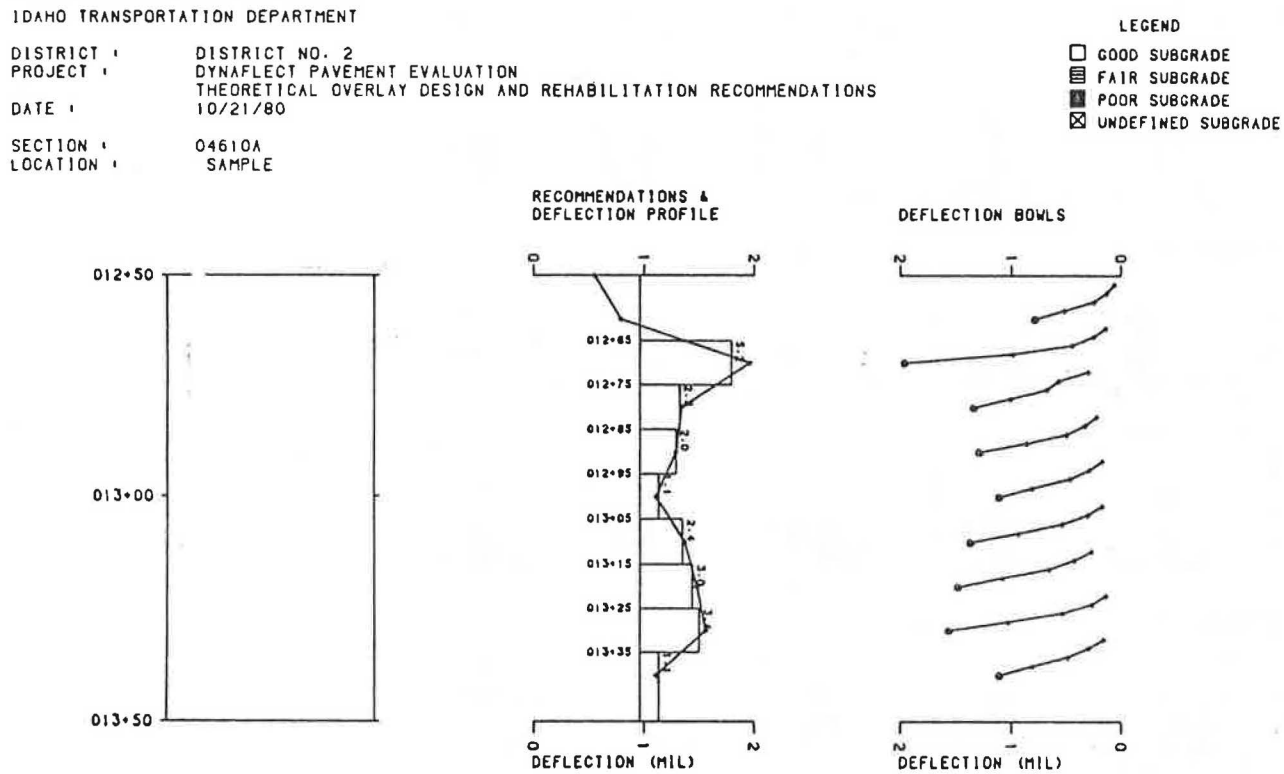
| MILEPOST | DYNAFLECT SENSOR READINGS NO.1 | NO.2 | NO.3 | NO.4 | NO.5 | WIC | SCI | BCI | SPD | YRS TO FAIL | OVERLAY THICKNESS | PAVEMENT SYSTEM CONDITION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66.60 | 0.71 | 0.64 | 0.54 | 0.41 | 0.32 | 1.01 | 0.07 | 0.09 | 73.8 | 8 | 6.93 | |
| 66.80 | 0.49 | 0.43 | 0.35 | 0.26 | 0.18 | 0.65 | 0.06 | 0.08 | 69.8 | 12 | 4.30 | |
| 67.00 | 0.35 | 0.30 | 0.22 | 0.15 | 0.08 | 0.52 | 0.05 | 0.07 | 62.9 | 21 | 0.00 | |
| 67.20 | 0.39 | 0.36 | 0.29 | 0.22 | 0.16 | 0.82 | 0.03 | 0.06 | 72.8 | 11 | 4.00* | |
| 67.40 | 0.45 | 0.42 | 0.35 | 0.27 | 0.19 | 0.51 | 0.03 | 0.08 | 74.7 | 12 | 4.55 | |

* INDICATES THAT THE MINIMUM/MAXIMUM AC OVERLAY THICKNESS IS RECOMMENDED

SUMMARY FOR SEGMENT NO. 5 OF THIS SECTION

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MEAN VALUE | 0.48 | 0.43 | 0.35 | 0.26 | 0.19 | 0.70 | 0.05 | 0.08 | 70.8 | 3.96 |
| MINIMUM | 0.35 | 0.30 | 0.22 | 0.15 | 0.08 | 0.51 | 0.03 | 0.06 | 62.9 | 0.00 |
| MAXIMUM | 0.71 | 0.64 | 0.54 | 0.41 | 0.32 | 1.01 | 0.07 | 0.09 | 74.7 | 6.93 |
| STD. DEVIATION | 0.14 | 0.13 | 0.12 | 0.10 | 0.09 | 0.21 | 0.02 | 0.01 | 4.8 | 2.50 |

Figure 8. Sample of POD graphical output.




based on the original work described by McCullough (9) and its subsequent expansion to include more recently developed methods of pavement materials characterization. Detailed description of one model employed in PPMIS can be found elsewhere (10).

### Rigid Pavement Condition Rating System

The existing form of the condition (cracking) index model was found to be inadequate for rigid pavements because it was developed primarily for flexible pavements. A discriminant analysis procedure developed for the Texas State Department of Highways and Public Transportation (11) was adapted to jointed concrete pavements as described in detail elsewhere (10).

### Partial Network Level Analysis

SYSTDY and SUMMARY programs were modified to operate with less than the standard number of inventory parameters (i.e., deflection, roughness, condition, and skid). This feature was thought to give more flexibility to ITD in the use of the system.

### Expansion of PPMIS Program Features

The inclusion of structural analysis models for rigid pavements in PPMIS required considerable expansion of the SYSTDY and POD programs. Some other expansions were also necessary as a result of the changes in analysis techniques employed. Details of these expansions can be found elsewhere (8,10).

## Application and Verification of Expanded and Modified Idaho PPMIS

### Network Analysis Application

To test the reasonableness of the expanded and modified portions of the Idaho PPMIS the Interstate field inventory data collected during the phase 1 project in 1979 were used as input for a number of runs of the new version of PPMIS programs.

Of chief concern was the reasonableness of the newly developed rigid pavement analyses. The 1979 inventory included the 216.8 miles of rigid Interstate pavements. These pavements could not be considered in the phase 1 verification runs because rigid-pavement analyses had not yet been developed and incorporated into PPMIS. The new expanded and modified PPMIS made possible the determination of the need (priority) for improvement, as indicated by the final index, on a network of pavements that contain both flexible and rigid sections.

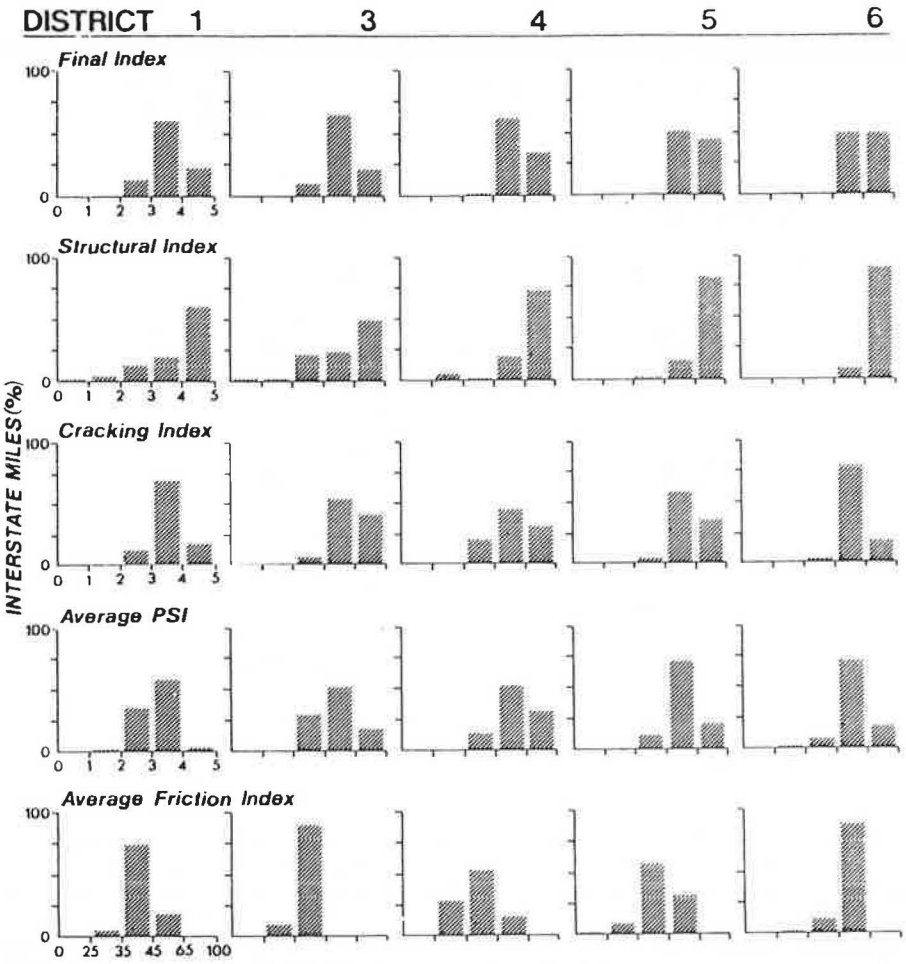
Figure 9 presents the summary results of the network analysis in terms of the distributions of final index, structural index, cracking index, average PSI, and average friction index for five districts in Idaho.

The comparison of final indices presented in Figure 9 indicates that districts 4, 5, and 6 are in much better condition than districts 1 and 3. This could perhaps be because district 1 and especially district 3 are the most highly populated districts in the state and, accordingly, would have the highest traffic volumes.

The district 6 Interstate mileage appears to be in the best structural condition; no mileage is in the structural index range of 0 to 2.9 and the district also has the highest percentage in the 4.0 to 5.0 range. The Interstate mileage in districts 1 and 3 is again in the poorest structural condition of all the districts in the state.

Figure 9 indicates that no section of Interstate mileage in the state has a cracking index between 0.0 and 1.0. District 5 appears to have the most Interstate mileage; the cracking index is between 4.0 and 5.0. The bulk of the Interstate mileage appears to be between 3.0 and 3.9.

Figure 9. Comparisons of Interstate mileage.




In terms of average PSI the Interstate mileage in district 1 was found to be in the poorest condition as compared with the other districts in the state. No Interstate mileage has an average PSI below 1.0 and only 2 miles appear to have an average PSI between 1.0 and 1.9. The bulk of the Interstate mileage has an average PSI between 3.0 and 3.9.

In terms of skid numbers, the district 6 Interstate mileage has only one mile below a skid number (SN) of 36 and is clearly the best in the state. Similarly, district 3 has by far the highest percentage between 36 and 45 and no mileage above a value of 46. This indicates that, although district 3 Interstate pavements are generally fair at the present time with respect to skid resistance, careful periodic monitoring is warranted to determine any changes.

These district comparisons can assist in determining initial budget allocations for improvement to the Interstate pavements among Idaho's districts. The initial allocations would be based on the estimated relative needs of each district for Interstate pavement improvements. A further refinement to this initial allocation could be effected by the inclusion of economic analysis and network optimization.

In addition to the network output shown in Figure 9, a more detailed output similar to the example given in Figure 3 was produced for each section on the Interstate system in the state. They were evaluated by ITD personnel and were found to be reasonable for ITD's purposes.

## Project Analysis Application

The testing and application of the project analysis portion of the Idaho PPMIS (i.e., program POD) was done by using flexible pavement data received from each district in the state. A test run was also made using an example of a rigid pavement.

The detailed deflection testing on the projects was conducted by ITD personnel and equipment. The projects (one in each district) had been selected by districts and generally were real projects scheduled for improvement in an immediate future.

The results of the program POD were discussed in detail with the districts and were found to be reasonable. The formats in which the results were presented were also found to be reasonable and helpful to the district materials engineers.

The POD analysis results for one concrete section in district 1 were also discussed with the IDT personnel. The results were generally found quite reasonable; however, a more thorough analysis covering a number of concrete sections is necessary before a final conclusion can be drawn. On the other hand, the SYSTDY program produced reasonable results for the concrete sections in the state by using the same procedures as in the POD program. This tends to in-

dicate that the POD program should produce reasonable results for concrete pavements as well as for flexible pavements.

INSTALLATION AND TRAINING COURSE

The modified and extended version of Idaho PPMIS program has been installed on ITD's computer facilities in Boise, Idaho, after the assessment of the results. Extensive test runs were made to debug the programs and to overcome the problems associated with installation of a software package on a different hardware. A 2-day training course was held to train the ITD personnel in the use of the system. Detailed engineering and software documentations along with user manuals were provided to the potential users in ITD to facilitate ease of use of the system.

The Idaho version of the new PPMIS program is now operational and is being used effectively by ITD personnel for the management of the state's pavement network.

ACKNOWLEDGMENT

We wish to acknowledge Brian Kerr, Kirk Smeaton, and Alan Sadowsky of PMS Ltd; our colleagues in ARE, Inc., specifically, Freddy Roberts and Frank McCullough; and Dean Tisdale, Bill Pardew, and Ruben Manubey of ITD for their invaluable assistance in this project.

REFERENCES

1. Pavement Management Systems International, Inc.; Austin Research Engineers, Inc. Documentation, Modification and Application of the Idaho PPMIS. Idaho Transportation Department, Boise, June 1980.
2. MACS Milepost and Coded Segment System. Idaho Transportation Department, Boise, 1978.
3. Pavement Management Systems International, Inc.; Austin Research Engineers, Inc. Supplementary Report for Comparing Various Dynaflect Units Used in the PPMIS Deflection Inventory Program. Idaho Transportation Department, Boise, Nov. 1979.
4. M.A. Karan, D.H. Kobi, C.B. Bauman, and R.C.G. Haas. Subjective and Mechanical Estimations of Pavement Serviceability for Rural-Urban Road Networks. TRB, Transportation Research Record 715, 1979, pp. 31-36.
5. D.H. Kobi and others. Data Inventory for Pavement Management. Paper presented at Annual Conference, Roads and Transportation Assn. of Canada, Regina, Saskatchewan, Canada, Sept. 1979.
6. D.H. Kobi. ARAN--An Integrated and Automated Road Inventory Tool. Paper presented at American Public Works Assn. International Public Works Congress and Equipment Show, Kansas City, Sept. 1981.
7. Pavement Management Systems International, Inc.; Austin Research Engineers, Inc. Serviceability (PSI)-Roughness Correlation Project for the State of Idaho. Idaho Transportation Department, Boise, Jan. 1981.
8. F.R.P. Meyer and M.A. Karan; Pavement Management Systems International, Inc.; Austin Research Engineers, Inc. Updated Serviceability (PSI)-Roughness Correlation Report. Idaho Transportation Department, Boise, Jan. 1981.
9. B.F. McCullough. A Pavement Overlay Design System Considering Wheel Loads, Temperature Changes and Performance. Univ. of California at Berkeley, Ph.D. Dissertation, July 1969.
10. Pavement Management Systems International, Inc.; Austin Research Engineers, Inc. Modification and Extension of the Idaho PPMIS. Idaho Transportation Department, Boise, June 1981.
11. M. Gutierrez de Velafco and B.F. McCullough. Summary Report for the 1978 Condition Survey in Texas. Center for Transportation Research, Univ. of Texas, Austin, Rept. 177-20, Dec. 1979.

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

# Rigid Pavement Network Rehabilitation Scheduling

MANUEL GUTIERREZ de VELASCO AND B.F. McCULLOUGH

**The development and application of a scheme, in the form of a computer program, to order the priority and schedule a set of rigid pavements for rehabilitation within a specified time frame and budget constraints are presented. The scheme makes use of a distress index to order the priority of a group of pavement sections and to decide when a pavement has reached its terminal condition. The distress index is calculated by combining into a single number the various distress manifestations that occur in a pavement section. The initial pavement condition is determined from field distress condition surveys and the future condition is determined by means of distress prediction models. The immediate application of the computer program is to generate lists of candidate pavements for rehabilitation; however, the use of the program can be extended to analyze the effect of several different budget policies on the condition of the pavement network.**

The need for better management tools to allocate money, staff, equipment, and materials in an efficient manner has become evident with the continuous increment of requirements to maintain and rehabilitate a pavement network.

A relatively small amount of research effort has been placed on restoration as compared with the provision of new facilities because most previous capital investments have been centered on construction of new roads. This trend is reversing, however, and the prime effort is shifting toward the maintenance and rehabilitation of existing pavements.

During the last decade, pavement management systems (PMS) have been applied successfully to improve the management and technology of pavements (1-3). Among the PMS studies, the methods for planning maintenance and rehabilitation in a pavement network have become relevant in recent years. The desired result from a network application is a work program for each year during an analysis period. However, different degrees of complexity can be achieved and, for an agency without PMS experience, starting with a simplified version and progressing in a staged