MAPCON: A Pavement Evaluation Data Analysis Computer System

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Described in this paper is a computerized pavement data analysis methodology called MAPCON. Pavement condition data are input and results useful for pavement management are produced. The MAPCON system was developed in a research project funded by the Federal Highway Administration. Eight state highway departments were studied to determine their pavement data collection and analysis procedures. New pavement analysis programs were developed, and existing programs were identified, tested, and modified. All of these programs (a total of 18) were incorporated into a microcomputer package that features menu-driven program flow and fully interactive data input. MAPCON guides the user through selection of analysis method, data entry, and analysis. The path taken by MAPCON is determined by the user's answers to questions presented on the screen. The type of data analyzed by MAPCON includes friction and skid, roughness, structural capacity, surface condition, or a combination of the last three. MAPCON is a set of tools useful to pavement management and design engineers. It is available for implementation and use by highway agencies. Because of the wide variety of existing pavement analysis techniques and ever-changing technology, continued support for further research and development of MAPCON is desirable. Pavement technology is also changing constantly and the MAPCON suite of analysis programs has the capability to change with the technology.

Pavement management is an important concept that involves many highway agency functions such as data collection, planning, research, design, construction, maintenance, rehabilitation, and others. Because of the broad implications for improving the efficiency of building and maintaining the highway pavement infrastructure, pavement management is a major area of emphasis in the United States. The objective of the research described in this paper is to provide highway agencies with a set of tools to reduce raw pavement condition data to suitable inputs for pavement management systems.

OBJECTIVE

Raw pavement evaluation data must normally be processed before it is input to a pavement management system (PMS). Data must be checked for accuracy, entered into a data base, analyzed, and summarized before the engineer can use them to list projects in order of priority or make decisions about rehabilitation. Modern transportable computers allow technicians and engineers to take a computer to the field for direct data entry. This paper describes a system of microcomputer programs to aid in converting raw pavement evaluation data to usable input for a PMS.

From 1979 to 1983, the Federal Highway Administration (FHWA), U.S. Department of Transportation, sponsored research with Pennsylvania State University (Penn State), to assemble several computer programs into a suite of programs called Methods for Analyzing Pavement Condition Data (MAPCON). In a followup project, ARE Inc. has further developed and improved the MAPCON system *(1)*. Three computer programs from the Penn State research were included in MAPCON. Twelve new analysis programs were developed by ARE Inc. and added to MAPCON. Three existing programs were identified, tested, and modified for use in the MAPCON system. This gave MAPCON a total of 18 analysis programs. ARE Inc. then integrated all of the programs into a user-friendly package for convenient use on microcomputers.

MAPCON features menu-driven program flow and fully interactive data input. The system is structured for easy addition of new programs. Also, because of its structure, MAPCON will continue to operate on a microcomputer regardless of the number of programs added.

State highway agencies were selected for participation in the project with ARE Inc. to give a broad spectrum of PMS data-collection equipment, procedures, and analysis techniques. Agency representatives received training in operating MAPCON, reviewed the system, and provided advice about how it could be improved to best fit their needs. These ideas are incorporated into the current form of MAPCON.

The MAPCON system contains procedures for the analysis of pavement condition data. The analysis methods are state of the art in pavement evaluation and design-data handling. Almost all of the basic types of pavement evaluation data analysis procedures are included in MAPCON's comprehensive suite of programs. General types of data analyzed by MAPCON include friction or skid, serviceability or roughness, structural capacity, and surface distress. Both rigid and flexible pavements may be considered. The program is user friendly and easy to learn and operate by anyone familiar with pavement evaluation and design concepts. The user does not need special computer expertise, but a working knowledge of MS-DOS (disk operating system) is helpful. MAPCON runs on IBM-PC compatibles using MS-DOS version 2.1 or greater. New pavement analysis programs may be introduced by simply adding them to the menus and providing a simple interactive data input routine (if desired). The analysis routines exist as individual executable files on computer disk. Only one routine is called into computer memory at a time so the maximum size of the entire MAPCON suite is virtually unlimited.

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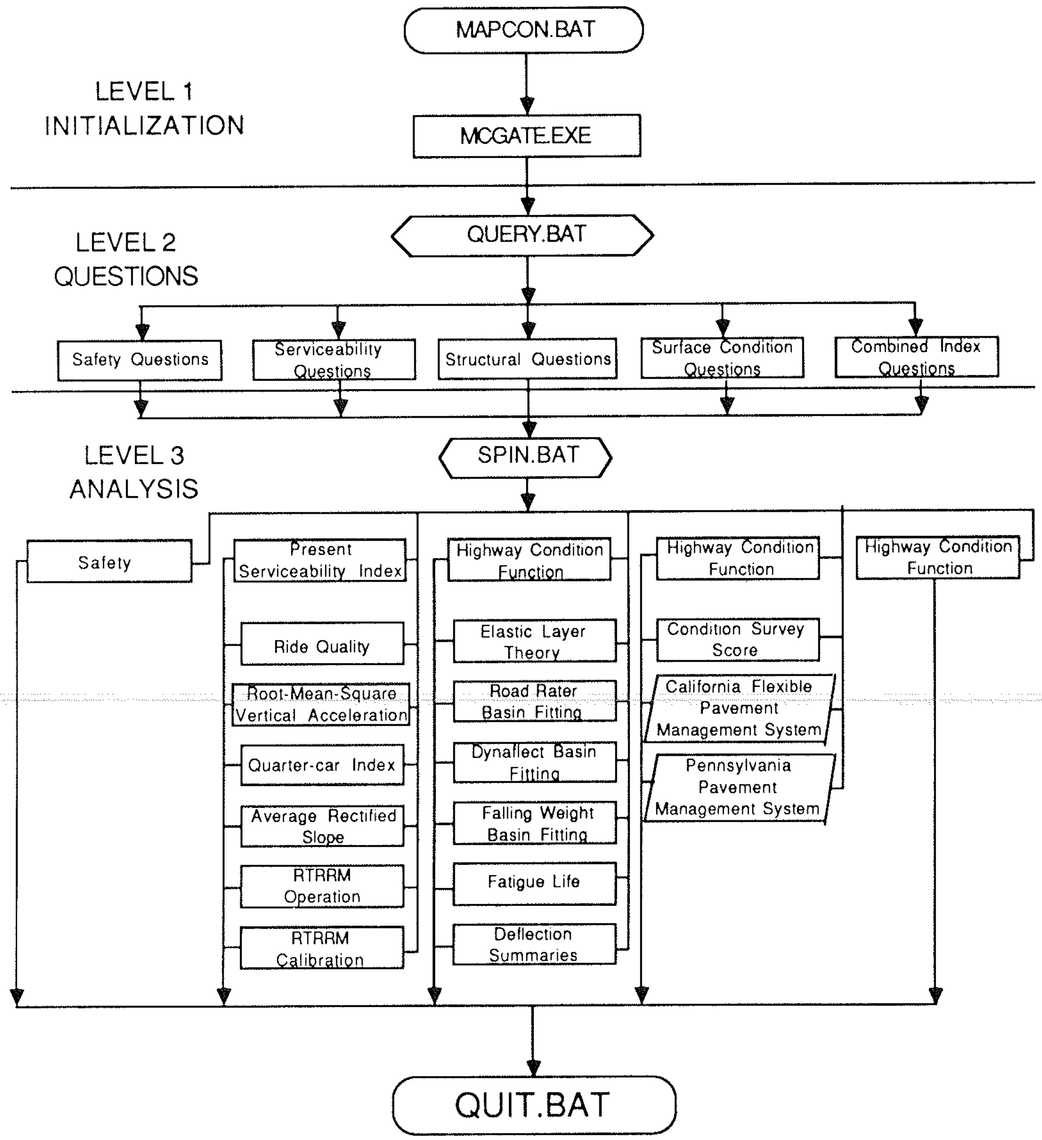

FIGURE 1 Flowchart of overall MAPCON system showing individual program modules.

ANALYSIS PROCEDURES INCLUDED IN MAPCON

MAPCON allows the user to select the desired analysis method, enter data, and perform analyses. Figure 1 is a diagram showing the basic flow of MAPCON. The user initially types the word "MAPCON". From there, the path taken by MAPCON is determined by the user's answers to questions presented on the screen. The initial question concerns the type of pavement data to be analyzed. The choices are

1. Safety,
2. Serviceability or roughness,
3. Structural capacity,
4. Surface condition, or
5. A combination of the last three.

Depending on the answer, MAPCON executes the appropriate path setting data-entry program. The user is presented with menus of options. His choices determine the type of analysis to be performed. The program then presents data-entry questions. Data checking is performed by reprinting the answers and allowing them to be changed. For the input of bulk data, such as pavement profiles or pavement texture data, the user has the option of entering data in the program or inputting the names of existing bulk data files. After data entry is complete, MAPCON executes the chosen analysis programs with the input data files.

A complete description of the operation of MAPCON and the algorithms used are given in the *MAPCON User's Manual (2)* and the *MAPCON Operations and Maintenance Manual (3)*. An overview of the programs and instructions for use are also in the User's Manual.

Pavement Safety Analysis

The safety-analysis routines involve the determination of friction and hydroplaning potential for a standardized tire, and the analysis of skid resistance/velocity relationships from friction measurements. The safety analysis paths in MAPCON are all included in a subprogram called SAFE; the flow is shown in Figure 2.

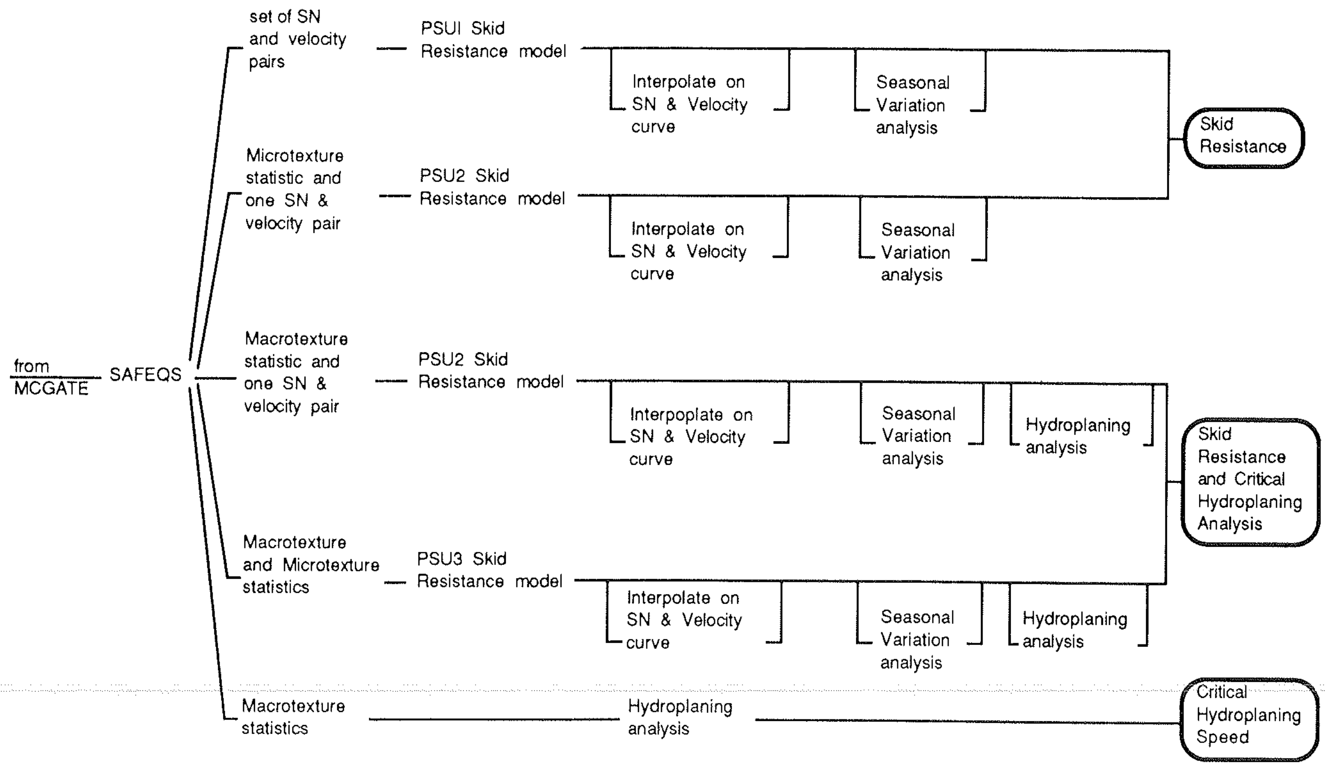

FIGURE 2 Safety analysis paths.

Program SAFE uses combinations of skid number with associated vehicle velocity and microtexture or macrotexture profile data to define a skid number/velocity relationship for a pavement. Routines are also included to calculate critical hydroplaning speed, given a macrotexture parameter.

Pavement Serviceability or Roughness Analysis

The concept of rating the present quality of a road is discussed in detail by Carey and Irick *(4)*. Present serviceability is defined as "the ability of a specific section of pavement to serve high-speed, high-volume, mixed (truck and automobile) traffic in its existing condition." As the term and its definition indicate, the present serviceability index (PSI) relates only to the condition of the pavement at the present time and not to its past or future condition. The present serviceability rating (PSR) is the mean of the subjective evaluations of present serviceability made by a human rating panel. The panel is intended to represent all highway users. The PSR (and therefore the serviceability) of a pavement has been shown to be directly related to pavement roughness, as measured by mechanical equipment, in a number of studies *(5–7)*. The paths available to perform serviceability and roughness analysis within MAPCON are shown in Figure 3.

Several types of data can be used to estimate serviceability. The most common types of data collected are

- Profile data collected by profilometers or by rod and level surveys.
- Roughness data collected using response-type road roughness meters (RTRRMs).

Profile data consist of pavement elevations collected at regular, closely spaced intervals along the traveled path of the road. It is generally not cost effective to collect profile data for an entire pavement network.

Response-type devices such as Mays Meters, Bureau of Public Roads (BPR) roughometers and Portland Cement Association (PCA) meters are cost-effective for collecting data on a network level, but the raw data cannot be used to estimate serviceability directly. RTRRMs measure the response of a vehicle to road roughness. The response for a given section of road will be different for each device used. The response of an RTRRM is therefore machine dependent and must be calibrated.

MAPCON contains several programs to evaluate profile data and calibration and operation data from RTRRMs. These programs are called PSI, RQ, VAARE, QIARE, ARSARE, RUNMM, and CALBMM, and are described as follows.

Program PSI contains routines for analyzing several types of data to get a present serviceability index. Data types include output from several types of RTRRMs, pavement profile data, and axle-body displacement data. Routines include simulations for ideal and conventional Mays Meter; CHLOE profilometer; and quarter-car, half-car, and full-car models. There is also a paver-grinder simulation routine.

Program RQ analyzes several types of data to give ride comfort statistics. One model included is the University of Virginia Ride Quality Model (8), which analyzes pavement profile data and root-mean-square body acceleration and roll rate data. Another model is the ISO Ride Quality Model (9), which uses pavement profile data and either a linear or a nonlinear transfer function.

Three programs use pavement profile data to produce pavement roughness statistics. These statistics can be used to calibrate RTRRMs. Program VAARE calculates the root-mean-

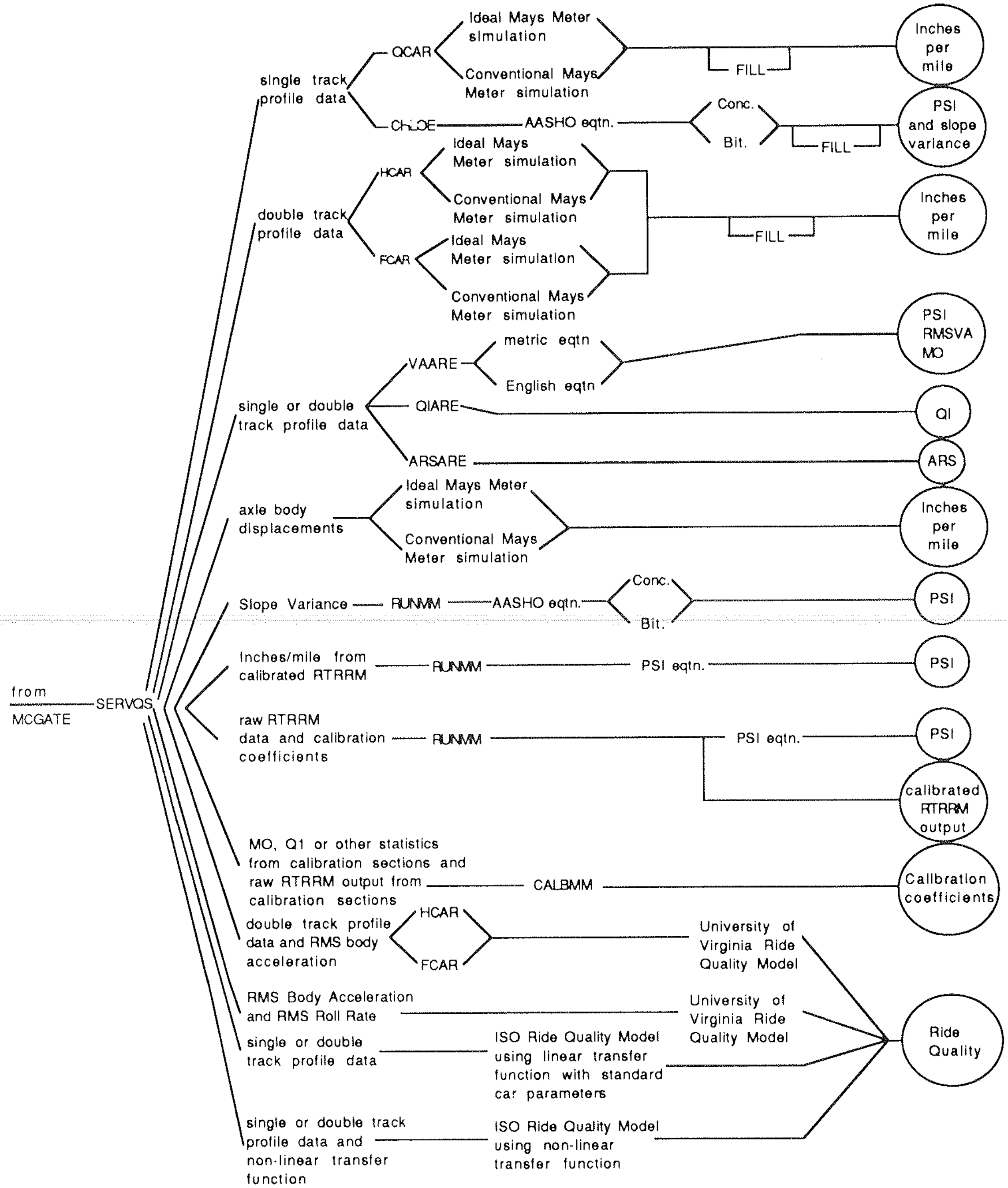

FIGURE 3 Serviceability analysis paths.

square vertical acceleration statistic (RMSVA). Program QIARE calculates a quarter-car index (QI). Program ARSARE calculates average rectified velocity (ARV) and average rectified slope (ARS) as defined by Gillespie, Sayers, and Segel *(10)*.

Programs CALBMM and RUNMM are used to develop RTRRM calibration coefficient files and convert RTRRM data to standard roughness statistics using these files. Calibration coefficient files can be set up using roughness statistics such as RMSVA, QI, ARS, ARV, or other statistics.

Pavement Structural Capacity Analysis

The purpose of structural capacity analysis is to determine the ability of a pavement to withstand loads. The primary types of data used to determine structural capacity are

- Modulus of elasticity values, Poisson's ratios, or other fundamental engineering properties of the pavement materials.
- Deflection data collected using multisensor devices such as the Dynaflect, road rater, or falling weight deflectometer.

MAPCON has several methods of evaluating data from both categories. The available structural analysis paths are shown in Figure 4. The programs used in the structural capacity paths are RRFIT1S, DYNAFIT, FWDUT1S, ELSYM5 (ELSARE), HCF, FATLIF, and GENDEF, which are all described in the following paragraphs.

Programs DYNAFIT, FWDUT1S, and RRFIT1S are used for interactive deflection basin matching for the Dynaflect, falling weight deflectometer, and road rater, respectively. These

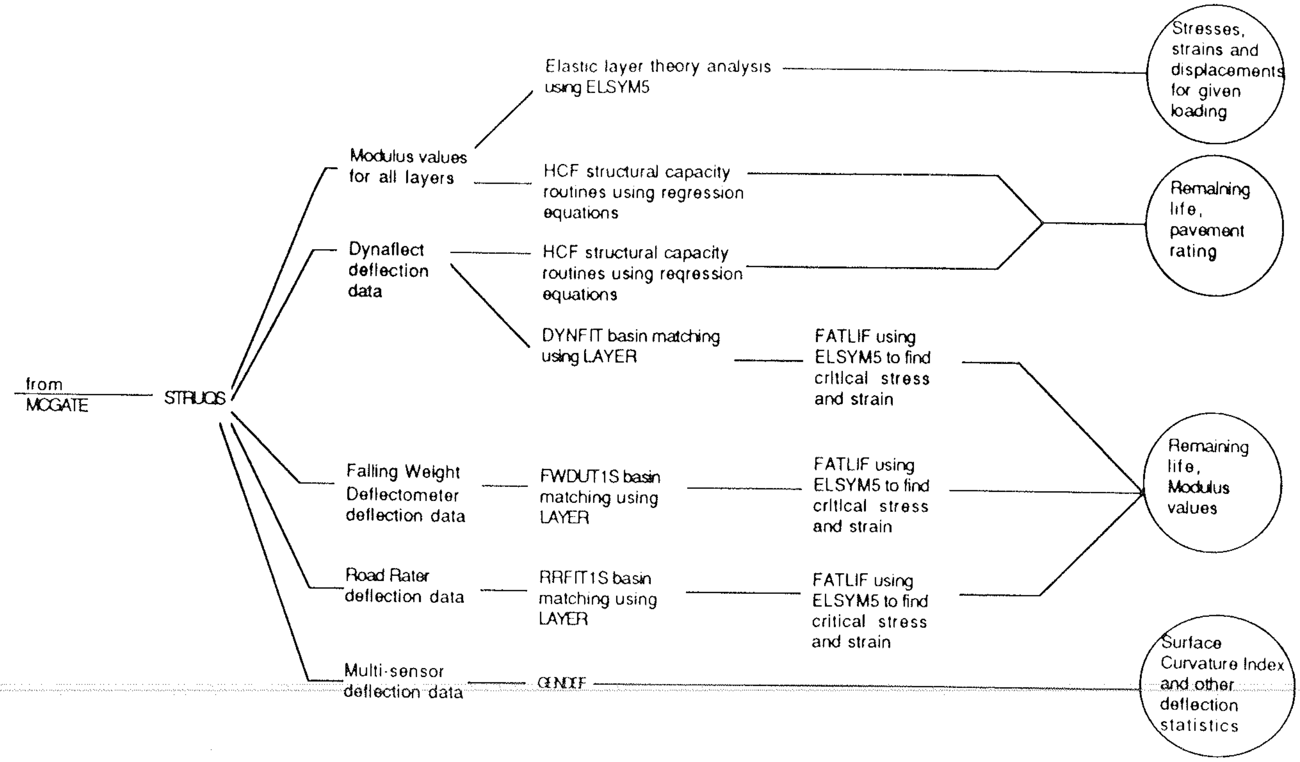

FIGURE 4 Structural capacity analysis paths.

programs use elastic layer theory to estimate a deflection basin. The input material properties are varied until the theoretical basin matches the measured basin. Each program has fully interactive data input and plotting of the calculated and measured deflection basins. They also have the capability to analyze pavement structures with a bottom layer of bedrock.

Program ELSYM5 contains routines for elastic layer theory analysis of a pavement structure. This program uses an input format developed by ARE Inc. It provides estimates of stresses, strains, and deflections at user-specified locations within a pavement system.

Program HCF uses simulated elastic layer theory analysis routines and fatigue-life equations to predict fatigue life from either Dynaflect deflections or input layer modulus values.

Program FATLIF uses the fatigue-life equations previously mentioned to predict pavement fatigue life. It reads input files created by the deflection basin matching programs, or by the user. Elastic-layer theory routines are called to find the critical stresses or strains used in the fatigue-life equations.

Program GENDEF takes any multisensor deflection-device data and calculates surface curvature index (SCI), base curvature index (BCI), and spreadability index (SPR). It calculates the mean and standard deviation of the sensor readings, SCI, BCI, and SPR for all the deflection basins in each section.

Pavement Surface-Condition Analysis

Surface-condition analysis involves the manipulation of data concerning distress manifestations that are present on the pavement surface. The surface-condition analyses included in MAPCON are shown in Figure 5.

Surface-condition data are used in MAPCON for two purposes:

1. To calculate a pavement-condition survey score, or pavement condition index; and
2. To create a data base for use in making PMS decisions.

Four paths are available in MAPCON for these purposes. The programs that make up these paths are HCF, FPMS, STAMPP, and SCORCS, all of which are described as follows.

Program HCF contains routines that calculate the pavement-condition index of the PAVER system *(11, 12)*. The result is a summary report of the distresses with their associated severities and extents and an overall pavement-condition index.

Program FPMS is a computerized pavement management system for flexible pavements developed by the state of California *(13)*. It features full-screen data entry and editing, data file manipulation, and determination of rehabilitation options.

Program STAMPP is also a pavement management system developed by the Pennsylvania Department of Transportation *(14)*. It has full-screen data entry, data file manipulation, and determination of rehabilitation options, and, like FPMS, is written in BASIC.

Program SCORCS calculates a condition survey score based on a user-defined equation. The user decides whether weighted distress deducts are added to or subtracted from a perfect pavement score. The user defines the perfect pavement score and inputs the weighted distress deduct values for each distress. The program then calculates overall pavement scores for use in prioritization of sections.

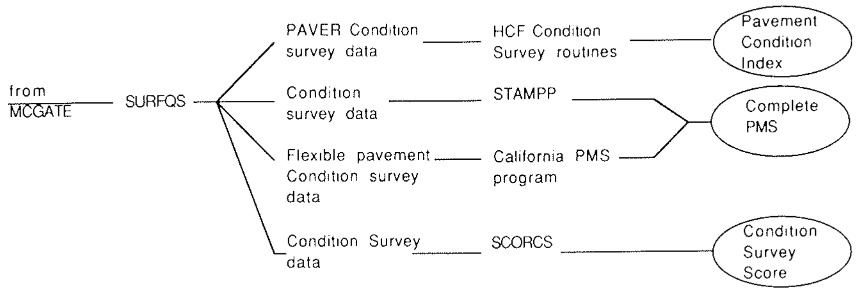

FIGURE 5 Surface-condition analysis paths.

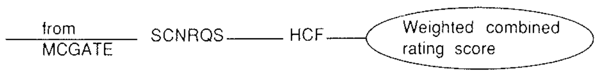

FIGURE 6 Combined structural capacity, condition survey, and ride-quality analysis paths.

Combined Analysis of Pavement Serviceability, Structural Capacity, and Surface Condition

The highway condition function (HCF) as already mentioned, is a computer program for establishing a pavement condition rating function. Figure 6 shows the path for this analysis. Measures of surface distress, structural capacity, and roughness are combined into overall indices that describe the condition of the pavement. The program uses any combination of one, two, or all three of the pavement condition parameters. Three forms of pavement condition summary index are output:

1. Weighted average,
2. Variance on minimum, and
3. Matrix rating value.

A weighting value is assigned to each of the pavement fitness measures and the average is computed for the weighted average statistic. The variance on the minimum uses the statistic with the lowest normalized value (i.e., the fitness measure indicating the worst-pavement condition) and adds the variance between the other pavement fitness measures to define the overall rating of the combined measures. In the matrix rating value approach, each of the pavement fitness measures is divided into six levels. The six levels for the three fitness measures define a $6 \times 6 \times 6$ matrix of pavement condition. The user can define a maintenance or treatment strategy for each of the cells in the matrix. These are used to define a dominant strategy for the treatment of the pavement.

The pavement condition function is modified with traffic and environmental factors to produce an overall highway condition rating score. A regression equation was developed to quantify the opinions of several highway engineers with respect to the weighting factors that should be used for the environmental and traffic factors. The user may readily change the default factors. For a detailed description of the highway condition function model, see Carmichael et al. *(15)*.

CONCLUSION

Summarized in this paper is a description of a computer program developed on a research project entitled "Procedures for the Evaluation of Pavement Condition Data." The research covered current practices in pavement-condition data analysis and incorporated relevant analysis procedures into a suite of computer programs, called MAPCON. This suite contains state-of-the-art procedures for all aspects of raw pavement-condition data analysis to produce inputs for pavement management systems.

The MAPCON suite of programs is useful to highway agencies in several respects. It is an automated method for analysis of raw pavement condition data to produce meaningful inputs to a pavement management system. MAPCON is also a useful tool for training pavement engineers and designers in the data types and methods used in pavement evaluation and rehabilitation. MAPCON is an analysis package to be used by highway agencies to reduce their pavement-condition data to usable indices and statistics.

Whereas each of the individual programs is powerful, the real strength of the MAPCON suite of programs is the ease of use. During the research project, more than 30 engineers from 8 states were trained to use the program. The training sessions generally consisted of one morning of introduction followed by structured use of the program in the afternoon. During the second day of instruction, the participants were experimenting freely with the program. With the ready availability of low-cost and powerful computers, programs such as MAPCON should significantly advance the state of the art in needed analysis tools. The boundaries of technology will continue to be pushed by research. MAPCON helps make new technology available to the highway practitioners.

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