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DEVELOPMENT OF AN EXPERT SYSTEM FOR CONCRETE PAVEMENT EVALUATION AND REHABILITATION

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DEVELOPMENT OF AN EXPERT SYSTEM FOR CONCRETE PAVEMENT EVALUATION AND REHABILITATION

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Abstract:

A comprehensive system has been developed to assist state highway engineers in project level evaluation and rehabilitation planning and design for high-type (Interstate) concrete pavements. The system utilizes information provided by the engineer to identify types of deterioration present and determine their causes, select rehabilitation techniques which will effectively correct the existing deterioration and prevent its recurrence, combine individual rehabilitation techniques for each traffic lane and shoulder into feasible rehabilitation strategies, and predict the performance of rehabilitation strategy alternatives. The pavement types addressed by the system are jointed reinforced concrete (JRCP), jointed plain concrete (JPCP), and continuously reinforced concrete (CRCP).

The evaluation and rehabilitation procedure has been developed in the form of an expert system, which simulates a consultation between the engineer and an expert in concrete pavements. The system was developed through extensive interviewing of and interaction with concrete pavement experts. In addition, a number of predictive models are incorporated into the system to show future pavement performance with and without rehabilitation.

The system has been developed in both manual and computerized form. An interactive computer program has been developed for each of the three pavement types addressed. The programs operate on any IBM-compatible personal computer.

Key words: Pavement, concrete, evaluation, rehabilitation, expert system

1.0 INTRODUCTION

1.1 Problem Statement and Research Objective

The objective of this research effort was to develop a practical and comprehensive system to assist practicing engineers in evaluating concrete highway pavements, identifying types of deterioration present and determining their causes, selecting rehabilitation techniques which will effectively correct existing deterioration and prevent its recurrence, combining individual rehabilitation techniques into feasible rehabilitation strategies, and predicting the performance of rehabilitation strategy alternatives.

The system is intended for use by state highway engineers in project-level rehabilitation planning and design for high-type (i.e., Interstate) conventional concrete pavements (JRCP, JPCP, and CRCP). The system does not perform thickness or joint design; the engineer must use existing design procedures to determine these details.

1.2 Research Approach

The evaluation/rehabilitation system has been developed in the form of a knowledge-based expert system, which simulates a consultation between the engineer and an expert in concrete pavements. The system uses information about the pavement provided by the engineer to guide him or her through evaluation of the pavement's present condition and development of one or more feasible rehabilitation strategies. The procedure was developed through extensive interviewing of and interaction with authorities on concrete pavement performance. In addition, predictive models are included to show future pavement performance both with and without rehabilitation.

Evaluation of a pavement and development of feasible rehabilitation alternatives is performed according to the following steps:

1. Project data collection.
2. Extrapolation of project condition over the entire project length.
3. Evaluation of present condition.
4. Prediction of future condition without rehabilitation.
5. Physical testing as needed.
6. Selection of main rehabilitation approach.
7. Development of detailed rehabilitation strategy.
8. Prediction of rehabilitation strategy performance.
9. Cost analysis of alternatives.
10. Selection of preferred rehabilitation strategy alternative.

A computer program has been developed for each of the three pavement types addressed. The programs operate on any IBM-compatible personal computer. Use of the computer program is highly recommended due to the complexity of the manual procedure.

2.0 KNOWLEDGE-BASED EXPERT SYSTEM APPROACH TO CONCRETE PAVEMENT EVALUATION AND REHABILITATION

2.1 Problem Statement

Rehabilitation design involves two activities: (1) <u>evaluation</u> of a pavement's present condition, and (2) development of <u>rehabilitation</u> alternatives which will cost-effectively <u>repair</u> the distress and <u>prevent</u> its recurrence [1]. Distresses are, to use a medical analogy, only symptoms of a problem, and treating the symptoms does not necessarily treat the problem. "Quick fix" repairs, which correct the existing distress without arresting the mechanisms which caused it, have a high probability of premature failure and thus are ultimately not cost-effective.

Rehabilitation design requires a good understanding of how pavements perform. However, concrete pavement performance is a complex phenomenon, which is influenced by a large number of factors relating to design, construction, materials, environment, and traffic. These factors interact to influence performance in ways which are not clearly understood. Thus, while some aspects of concrete pavement performance can be explained by mechanistic models and well established principles (e.g., calculation of stresses and fatigue damage), many other aspects cannot.

2.2 Expert System Approach to Engineering Problem Solving

In many areas of engineering, problem solutions are arrived at by relying on two different types of knowledge: (1) deterministic knowledge, which is that body of information which is widely accepted by and available to engineers in the field, and (2) heuristic knowledge, which is the subjective knowledge possessed by individual engineers, characterized by beliefs, opinions, and rules of thumb [2]. Difficult engineering problems typically cannot be solved with deterministic knowledge alone, for two major reasons. First, the problem may be so complex that available deterministic knowledge is incomplete. Second, many engineering problems do not have clear-cut right and wrong answers. Finding a "good enough" answer or selecting the best option from among a number of alternatives demands that the engineer apply good judgment. This too requires considerable technical skill on the engineer's part, as these decisions must be based on familiarity with the domain and experience in solving similar problems.

While deterministic knowledge is preservable in references and textbooks, heuristic knowledge definitely is not. Since it is acquired through individual experience, it is not easily communicated to others and, as experienced engineers retire, it is often lost. The challenge of organizing and preserving heuristic problem-solving knowledge is the basis for development of a relatively new type of engineering tool known as "knowledge-based systems." These are computer programs in which heuristic knowledge which has been acquired from humans is utilized to solve problems which are intractable with a purely deterministic approach. A subset of knowledge-based systems are "expert systems," which employ both the knowledge and reasoning methods of human experts.

2.3 Expert System Approach to Pavement Evaluation and Rehabilitation

Pavement evaluation is a diagnostic activity, similar to medical diagnosis, in which conclusions about the pavement's condition are drawn from an examination of relevant factual data. Several approaches exist for performing diagnostic activities with expert systems. The approach selected was to develop a decision tree for each major problem area of concrete pavement performance (roughness, structural adequacy, etc.). Decision trees permit both factual information and reasoning processes to be conceptually expressed and graphically illustrated in a form which is easy to understand, examine, and revise. The paths of the decision trees lead to one or more sentences of text explaining the deficiencies that exist and the factors considered in identifying them. These conclusions are represented by a three-letter code for the major problem area and the number of the specific conclusion reached. The decision tree for structural adequacy of JRCP is shown in Figure 1 as an example.

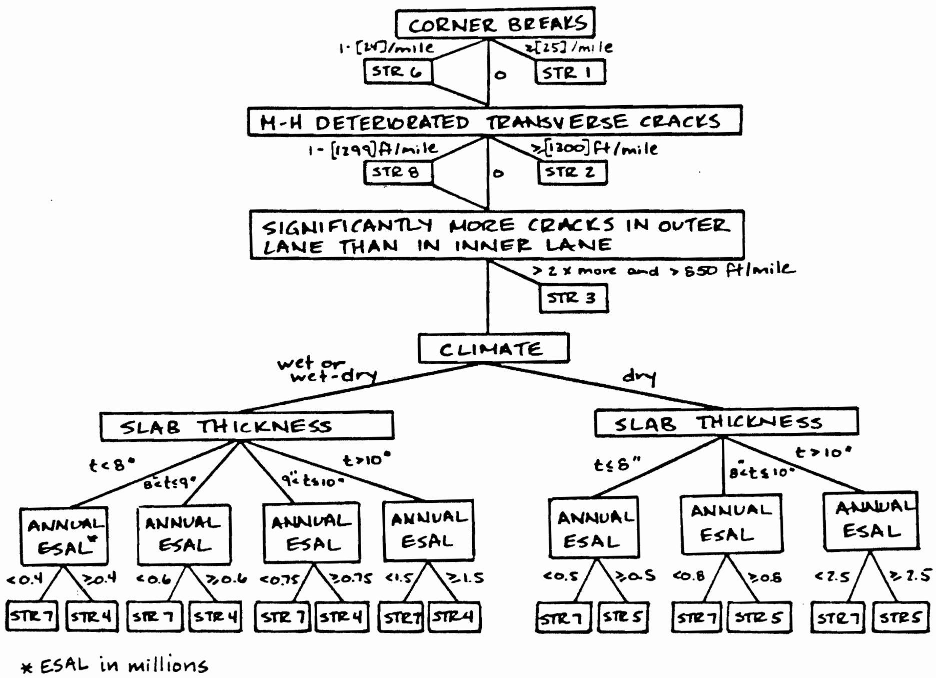

Figure 1. JRCP Structural Adequacy Decision Tree.

A pavement evaluation system which can only identify current rehabilitation needs has limited usefulness as a pavement management tool. What about a pavement that does not need rehabilitation now, but will within the next five years? What about a relatively new pavement which does not exhibit much visible distress, but which is inadequately designed or constructed to withstand the traffic loadings and environmental influences which will act upon it over its design life? Deterministic knowledge can be applied here, in the form of existing models for predicting concrete pavement performance. A number of predictive models for key concrete pavement distress types are employed project the future condition of the pavement without rehabilitation. The system uses these predicted values to "re-evaluate" the pavement each year for the next twenty years into the future, and identify the years in which deficiencies in the various problem areas will occur. By combining deterministic and heuristic knowledge, the system produces a more comprehensive and useful evaluation than would be possible using either type of knowledge alone.

Unlike evaluation, rehabilitation strategy development is a <u>design</u> activity, in which the engineer generates a strategy that satisfies the repair and/or improvement needs identified by the evaluation. Whereas evaluation generally considers a limited set of potential problems, rehabilitation design involves a huge number of combinations of many individual rehabilitation techniques. Generating and evaluating all the possible combinations of techniques would be a formidable task even for a high-speed computer, if done using conventional programming methods. Using an expert system approach, however, rehabilitation strategies can be developed much more quickly and easily by generating only feasible combinations of techniques, thus greatly reducing the number of strategies which the engineer must consider. This is done by applying restrictions on the generation of strategies which reflect heuristic knowledge about the compatibility of various techniques.

After one or more feasible rehabilitation strategies has been developed, the engineer must still choose the best alternative on the basis of life-cycle cost and other selection criteria. However, the engineer cannot perform a life-cycle cost comparison of alternatives without some idea of their expected lives. Deterministic knowledge can be applied here, by employing available models for predicting rehabilitation performance in terms of key distress types. Several such models were developed in this study and incorporated in the system. Thus in rehabilitation as in evaluation, deterministic and heuristic knowledge are combined to improve the quality of the problem solution.

2.5 Implementation of the System

One approach to knowledge-based system development is to implement a prototype with a commercially available, off-the-shelf software tool known as a "shell" which provides a suitable development environment (text editor, compiler, etc.), and then to rewrite the system for maximum efficiency when most of the difficult development is finished [3]. Initially, a shell was used to develop a demonstration prototype for the a portion of the system. The shell used was Insight 2+, developed by Level V Research, Inc. Insight 2+ is a production-rule-based system shell, meaning that knowledge is expressed in terms of "if-then" rules. To incorporate the decision trees into the Insight 2+ shell, each path down each tree (a path being composed of a set of nodes and connecting branches terminating at a conclusion) was programmed as a single rule. The decision trees impose a structure on the solution strategy which would not exist in a typical production rule system.

Although the production rule approach employed using Insight 2+ was helpful in initial prototyping, it soon became too restrictive for continued development of the system. Representing the decision trees with a set of rules was inefficient and unwieldy. Long compilation and execution times slowed the development of the system and detracted from the program's ease of use. It was also very difficult to interface the decision trees with other sections of the system (e.g., data entry and retrieval). To circumvent the limitations of the system as implemented in the shell, the system was rewritten in Pascal. This transformation changed the system from a traditional production rule system to a hard-coded system. Hence, some of the transparency of the knowledge was lost, and modifications became more difficult. These problems were more than offset, however, by the increased ease of interfacing the different parts of the system, the ease of programming the predictive models for future performance with and without rehabilitation, and the tenfold increase in execution speed.

3.0 DESCRIPTION OF EVALUATION AND REHABILITATION SYSTEM

The expert system consists of three separate, stand-alone evaluation/ rehabilitation systems, one for each of three concrete pavement types (JRCP, JPCP, and CRCP). The systems all follow the same steps described here.

3.1 Project Data Collection

The engineer collects key inventory (office) and monitoring (field) data for the project. Inventory data includes design, traffic, materials, soils nd climate. Monitoring data includes distress, drainage characteristics, rideability, and other items collected during a field visit to the project. Monitoring data is collected by sample unit; a sufficient number of sample units distributed throughout the project's length should be surveyed to obtain an accurate representation of the project's condition. The data are entered into a personal computer using a full-screen editor.

3.2 Extrapolation of Overall Project Condition

The overall condition of the project is extrapolated from the sample unit monitoring data and extrapolated distress quantities are summarized.

3.3 Evaluation of Present Condition

The engineer utilizes the evaluation decision trees to analyze all of the data and develop a specific detailed evaluation in several major problem areas, including roughness, structural adequacy, joint deterioration, foundation movement, skid resistance, construction deficiencies, drainage, loss of support, joint sealant condition, concrete durability, and shoulder condition. From the evaluation, a set of evaluation conclusions is produced for each traffic lane and each shoulder.

3.4 Prediction of Future Condition Without Rehabilitation

Based on the current traffic level (annual 18-kip ESAL) and the anticipated ESAL growth rate, the future condition of the pavement without rehabilitation is predicted. Faulting, cracking, joint deterioration, pumping, and present serviceability rating are projected for jointed pavements (and punchouts for CRCP) and the years in which they will become serious problems are identified. The predictive models used are calibrated to the existing condition of the pavement at the time of the survey.

3.5 Physical Testing As Needed

The initial data collection does not require physical testing. Based upon the available information, the engineer identifies types of physical testing needed to verify the evaluation recommendations and to provide data needed for rehabilitation design. Testing may include nondestructive deflection testing, coring/material sampling and laboratory testing, and roughness and friction measurement. Types of deficiencies which may warrant physical testing include structural inadequacy, poor rideability, poor surface friction, poor drainage conditions, poor concrete durability ("D" cracking or reactive aggregate distress), foundation movement (due to swelling soil or frost heave), loss of load transfer at joints, loss of slab support, joint deterioration, and evidence of poor joint construction.

3.6 Selection of Main Rehabilitation Approach

Based upon the evaluation results, the engineer then interacts with the system to select the most appropriate main rehabilitation approach for each traffic lane and shoulder. These include all 4R options: reconstruction (including recycling), resurfacing (with concrete or asphalt), or restoration. The decision tree developed to assist the engineer in selecting the most suitable rehabilition approach for each lane is shown in Figure 2.

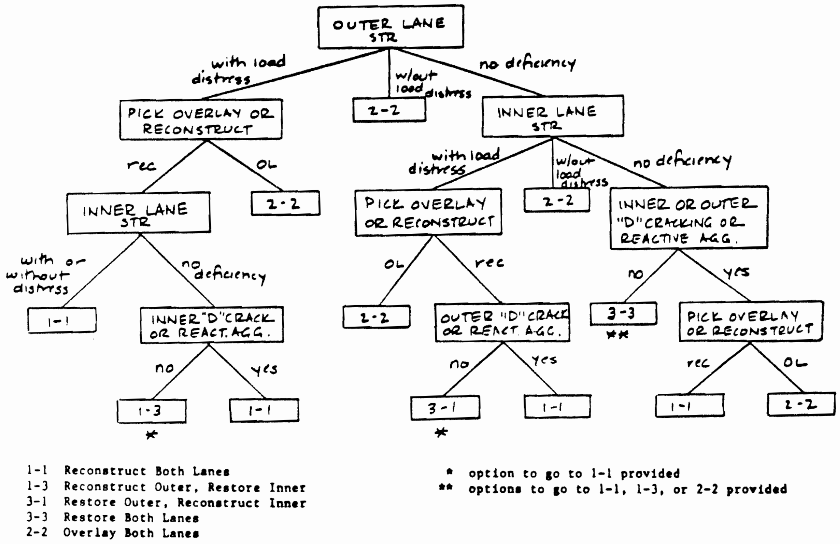

Figure 2. Decision Tree for Selection of Main Rehabilitation Approach.

3.7 Development of Detailed Rehabilitation Strategy

Once an approach is selected for each traffic lane and shoulder, the engineer proceeds to develop the detailed rehabilitation alternative, by selecting a feasible set of individual rehabilitation techniques to correct the deficiencies present. This may include such items as subdrainage, shoulder repair, full-depth repairs, joint resealing, etc. This is performed for each traffic lane and shoulder by interaction with the system. A set of decision trees has been developed to guide the rehabilitation strategy development process for traffic lanes and for adjacent shoulders.

3.8 Prediction of Rehabilitation Strategy Performance

The future performance of the developed rehabilitation strategy is then predicted in terms of key distress types for twenty years into the future, based upon assumed traffic growth. For concrete restoration, overlays and reconstruction, faulting, cracking, joint deterioration and present serviceability rating (and punchouts for CRCP) are projected. For asphalt overlay alternatives, rutting and reflection cracking are projected. The engineer evaluates the results and determines whether or not the proposed alternative provides an acceptable life. If so, a cost estimate can be prepared based on computed repair quantities. If not, the engineer can revise the rehabilitation alternative.

3.9 Cost Analysis of Alternatives

Approximate quantities for each rehabilitation technique included in the alternative strategy are computed from the extrapolated distress quantities for each lane and shoulder. The engineer then computes the total cost for each item and totals all costs for the strategy. The engineer determines the life of the rehabilitation from the projected deterioration information and computes an annual cost for the alternative.

3.10 Selection of Preferred Rehabilitation Strategy Alternative

Typically two to four feasible rehabilitation alternatives exist for a given project. To select the preferred alternative, the engineer must consider not only life-cycle cost but also constraints that exist for the project, such as traffic control, construction time, available funding, etc. Based upon estimated initial and annual costs, expected life and performance

2. Life-cycle cost analysis could be added to the system, if consideration is given to addressing unequal performance periods of different alternatives and additional costs that cannot now be computed by the system (e.g., bridge clearance, guardrail replacement, side slope improvements, traffic control, user-related costs).

3. Delay of rehabilitation. The system currently assumes that the rehabilitation work will be performed immediately after the evaluation, which is almost never the case. Routines need to be added to allow the engineer to specify the year of rehabilitation and have the system design rehabilitation strategies appropriate for the pavement's projected condition in that year. This will be difficult because predictive models are not now available for some distresses.

4. Improved predictive models. Many models were utilized to predict the future performance of the existing pavement (without rehabilitation) and the rehabilitated pavement. Most of these models have significant limitations, and are not applicable nationwide over the range of climatic zones. The development of improved models is a necessity to improve the validity of the system. These may best be developed for individual states or regions of states (e.g., the southeastern United States). The most deficient area of the existing models is in predicting the effect of retrofit subdrainage on pavement performance.

5. Other rehabilitation techniques which are not now included in the system could be considered if performance predicition models for them become available. Some techniques that could be added include fabrics, interlayers, or sawed and sealed joints in AC overlays, and CRCP overlays.

6. Physical testing recommendations could be improved and incorporated directly in the system. This could be a major work effort if physical testing recommendations are provided in great detail with recommended procedures for NDT evaluation, coring, materials testing, roughness and friction measurement, etc.

7. Extension of the system to existing AC overlaid concrete pavements. The system currently is restricted to pavements in their first performance period. Many concrete pavements exist that have been overlaid with AC already and are in need of further rehabilitation. Work on this addition to the system is currently underway at the University of Illinois.

8. Adaptation of the system to different pavement geometries (e.g., other than two lanes in each direction). This would make the system more applicable to the variety of geometries of concrete pavements throughout the United States.

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