Incorporating Expert System Concept into Pavement Treatment Strategy Selection

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ABSTRACT: Pavement preservation treatment selection is a complex process which involves many factors ranging from pavement engineering to economic analysis. To determine the most preferable treatment is very challenging to many pavement engineers, especially for someone with limited experience. Most states or local agencies utilize either decision trees or decision tables to assist with the treatment selection. However, there are some disadvantages of using these decision trees or decision tables. This paper proposes to incorporate the expert system concept into the pavement treatment selection process. The California Department of Transportation (Caltrans) decision tables for treatment selection have been converted to a prototype expert system which includes a user interface, an inference engine, and a knowledge base. The prototype system allows one to evaluate various treatment alternatives. The best alternative based on user provided roadway conditions and weighting scores can then be selected by the expert system. The system can help inexperienced engineers to make a better choice; it can also help streamline the decision making process for seasoned pavement engineers.

INTRODUCTION

Most states or local agencies utilize either decision trees or decision matrices to assist with the treatment selection that would satisfy specific conditions or constraints. These methods are generally suitable for local practices and easy to use. The major disadvantages are that they do not always consider all the important factors or ways to handle multiple distress types, and/or limit the use of various innovative treatments.

California Department of Transportation (Caltrans) has published a framework for treatment strategy selection in the Maintenance Technical Advisory Guide – MTAG (Shatnawi 2008). It provides a worksheet which allows one to compute the rankings of treatment alternatives based on their scores on benefit-cost ratio, life cycle cost, constructability, and the like. The problem with the MTAG treatment selection is that it is difficult and time consuming to fill out the worksheets with meaningful weighting factors for objectives, and to input weighting scores for each alternative. To assist filling in the weighting factors and scores, an expert system approach has been developed.

Use of expert systems was originally started in 1960s (Rheingold 1984). It already has many applications, such as in medicine, oil industry, and financial investing. Also, several expert systems have been developed in the fields of transportation. For example, in 1996, EXSPAV was developed for use in flexible pavement and overlay design. This expert system helps transfer and facilitates the knowledge of experts to the hands of the less experienced design engineer (Khedr et. al. 1996). In 2006, an expert system for recommending speed limits in speed zones was developed. Based on input from users, the expert system employs a decision algorithm to advise the user of the speed limit of the specific road section of interest (Srinivasan 2008). In 2006, an expert system was also developed to support site investigation for safety improvement (Kwasniak et. al. 2006).

The expert system approach can supplement less experienced personnel with abundant knowledge in a specific field. In addition, it can also provide a steady, unemotional response at any times. The purpose of this paper is to incorporate expert system concept into pavement treatment strategy selection process. A prototype expert system is currently under development at the California Pavement Preservation Center. This expert system uses the guidelines provided by the MTAG and can assist pavement engineers in selecting an appropriate pavement treatment strategy.

EXPERT SYSTEM VERSUS TRADITIONAL APPROACH

The procedures of solving problems in an expert system are different from a conventional approach. The conventional approach typically applies specified procedures to inputted data, and then outputs the calculated results. Most conventional approaches provide computed results without explanation of the reasoning. The conventional approaches are good for numerical computations but they lack logical reasoning (rules) that an expert system has. It is generally difficult for inexperienced persons to make a decision for a specific problem without the guidance or support of an expert.

The expert system approach can handle complex, real world problems using a computer model along with some logical reasoning based on the knowledge of human experts. These experts are people who are very good at solving specific types of problems because they have detailed specialized knowledge and extensive experience. The expert system can typically reach the same or similar conclusions the human expert would have reached if faced with a same problem.

An expert system is normally based on logical facts and expert knowledge (rules). It can also deal with uncertainties as an expert can. It is a part of broad Artificial

Intelligence (AI) approach that includes pattern recognition, learning, searching, reasoning, etc. The expert system approach composes three major components including: (a) knowledge base, (b) rule based inference engine, and (c) an interactive computer-based user interface.

INCORPORATE EXPERT SYSTEM INTO DECISION MAKING PROCESS
A framework of utilizing an expert system approach to select pavement treatment selection is illustrated in Figure 1. It includes a user interface, an inference engine, a knowledge base which stores knowledge from experts and/or experienced engineers. The process of deriving a recommended pavement preservation treatment, based on the user's inputs, is illustrated in Figure 2.

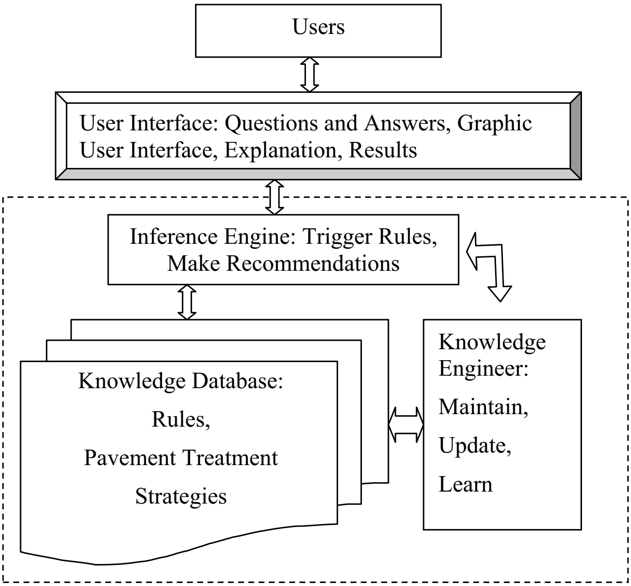

Figure 1. A Schematic Design of Pavement Treatment Selection Expert System

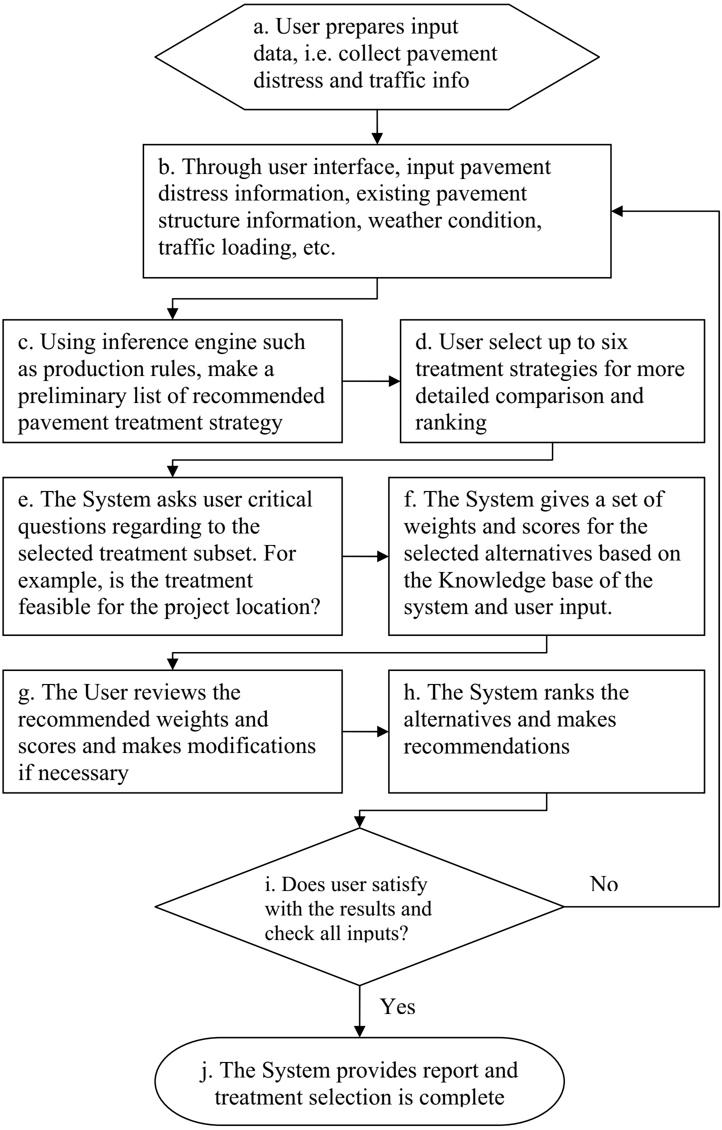

Figure 2. A flowchart for Using Expert System to Select Pavement Treatment

To create the system, a set of production rules needs to be created. Caltrans has a decision table to help the user select proper treatments as a function of the different types of distresses (except for cracking), weather, and traffic. Caltrans also has a similar table which shows appropriate treatments for different cracking related distresses (Shatnawi 2008). The system production rules generally have the following format:

If pavement is in *X* conditions, then treatment *Y* is good option.

Each treatment has a property table, which is in a database format and stored in the system knowledge base. The properties of treatments normally include pavement life extension, unit cost, constructability, environmental impact, etc. In addition, the knowledge base is expandable which means that new rules and new properties can be added to the system knowledge base in the future. The system's inference engine uses the production rules to help recommend weight and score for suitable alternatives. It can also recommend pavement treatment based on ranking results from the system.

The principle of scoring and ranking the alternatives is based on expert opinions. Based on surveys from various experts who are experienced in the field of pavement preservation and maintenance, a set of comparison criteria, including performance assessment, constructability, and customer satisfaction attributes, was developed to evaluate different treatment alternatives.

The system generates ranking of alternatives based on the utility theory by the following method:

$$PV_j = \quad A_i X_{ij}$$

where j = alternative number, such as 1, 2, 3, etc.;

PV_j = the priority value of alternative *j*;

A_i = the weight for alternative comparison criterion *i*; and

X_{ij} = the value for comparison criterion *i* for alternative *j*.

The default weighting values of comparison criterion (A_i) incorporated years of performance evaluation of various treatments and experts' opinions. The users can make modifications to reflect their local knowledge and experiences.

The values for comparison criteria, such as X_{ij}, are the scores of alternatives for comparison criteria. A better alternative should have a greater value of X_{ij}. If the value of a comparison criterion is qualitative, it is converted to a numerical value. The following rules are used to convert qualitative description to a numerical value and to normalize X_{ij}.

- A quality value of a treatment alternative is described as having six different levels: Excellent, Very Good, Good, Fair, Poor, and very poor. The six levels from excellent to very poor are converted into values of 5, 4, 3, 2, 1, and 0.
- The numerical values are normalized by dividing the individual score values by the average of scores for all alternatives.

$$X_{ij} = X_{ij} / (\quad X_{ij} / n)$$

where *n* represents the number of alternatives compared

Most scores, such as extended pavement service life, cost benefits, are calculated based on the treatment properties stored in the knowledge base. These values can be modified to reflect local and specific project scenarios.

EXAMPLE PROBLEM

This section illustrates an example of using the system to solve a treatment selection problem. Figure 3 shows the distresses and conditions of a pavement segment that are checked by a user through the system's user interface.

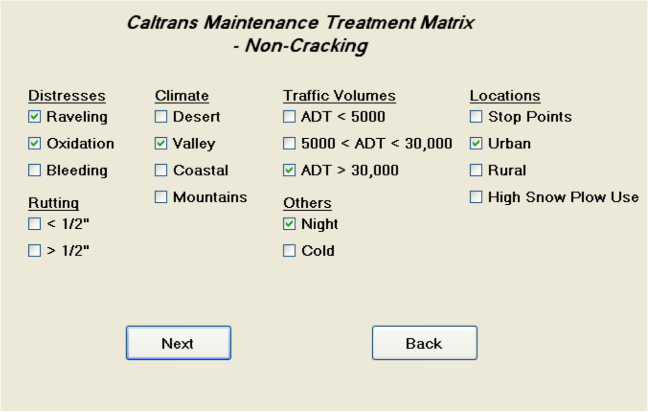

Figure 3. Example Pavement Distress and Condition User Interface

Based on the user checked data, preliminary suitable treatments shown in Figure 4 are provided by the system for further analysis. In this example, two treatments, Type II Microsurfacing and conventional thin lift overlays, are suitable for the roadway conditions.

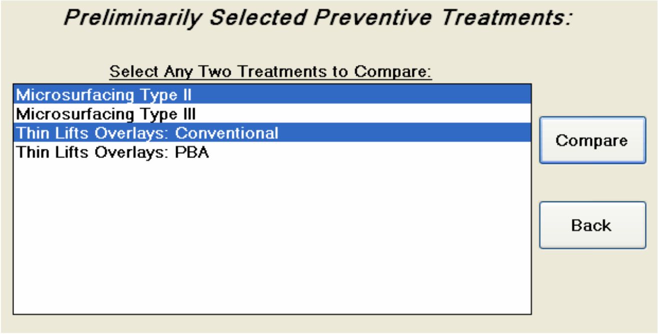

Figure 4. Example Preliminarily Selected Suitable Treatments

The suitable treatments can be further compared and ranked by the system. The proposed approach is to recommend weights for comparison criteria and scores for alternatives based on expert opinions and relevant properties of alternatives. Sample weights, scores, and recommendation from the system are illustrated in Figure 5. The Type II Microsurfacing is recommended by the system based on the calculated total scores.

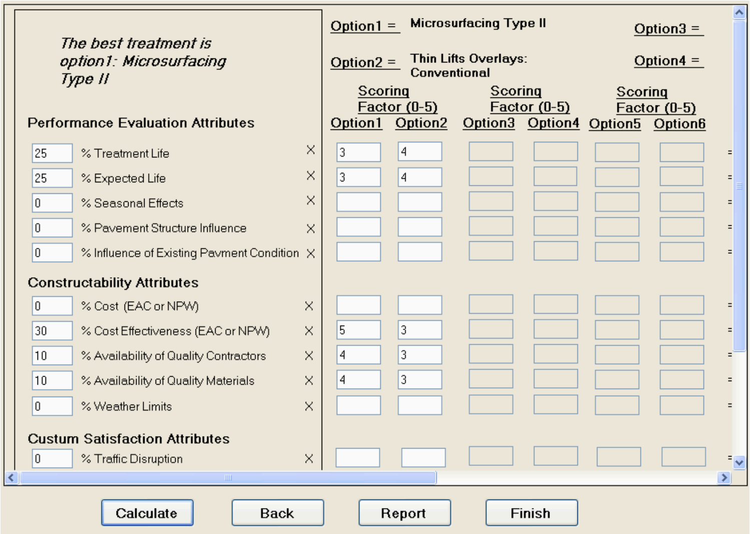

Figure 5. Sample Weights and Scores for Treatments Comparison

CONCLUSIONS

The proposed expert system may have a potential in improving the current Caltrans' pavement preservation treatment selection process. It can help not only inexperienced engineers to make a right choice, but can also support seasoned engineers streamline and explicitly present their decision making process for strategy selection.

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Effect of De-Icing Chemicals on Crack Sealant Performance in Colorado, USA

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ABSTRACT: Crack sealants prevent moisture and debris intrusion into pavements. The length of time that crack sealants are effective is important to highway agencies. Many highway agencies utilize a magnesium chloride solution to prevent snow and ice accumulation on roadway surfaces. It has been reported that this de-icing solution leaves a residue inside unfilled cracks in asphalt pavements, potentially affecting the performance of crack sealants. The purpose of this study was to assess the effect of magnesium chloride application on the performance of two types of crack sealants at two elevations in Colorado, United States.

The experiment was designed to evaluate the association between crack fill remaining over a three year period and two different crack sealants, with and without exposure to magnesium chloride. Using factorial ANOVA, a statistically significant difference ($p < 0.05$) between the two crack fill products was observed at both elevations; however, the effect of magnesium chloride was only observed for the crack sealants at the higher elevation.

INTRODUCTION

One of the largest investments in the U.S. has been construction of the interstate highway system (FHWA 2000). With over 71,000 miles of paved roadway surfaces, construction costs of the interstate highway system are estimated to be over 129 billion dollars from 1958 to 1991 (FHWA 2000). The vast majority of new construction is complete; however, engineers are facing a new problem, how to effectively and efficiently preserve and maintain it (FHWA 2006).

Throughout the history of highway construction, asphalt has been widely used for state and federal departments of transportation (USDOT, FHWA et al. 1998). Asphalt provides a flexible, smooth, durable, and cost effective material to construct road surfaces (Johnson 2000). However, issues associated with asphalt integrity include cracking and moisture-induced damage. There are three primary techniques used for pavement preservation and maintenance in Colorado, crack sealing, chip seals, and thin hot mix asphalt overlays (Shuler, CDOT et al. 2006). This experiment concentrates specifically on crack filling and focuses on assessing two similar industry products, named A and B. The purpose of this study is to evaluate the effect of magnesium chloride on the performance of these two products at two different locations in Colorado, USA (Shuler, CDOT et al. 2006).

Rationale for Pavement Preservation Evaluation
To date, no studies have identified the association between pavement preservation crack fill materials and exposure to magnesium chloride (MgCl) among high altitude highways. Concerns regarding asphalt integrity post-exposure to MgCl are anecdotal, often stemming from concerns described by state and federal maintenance workers. The rationale for this study is to better our understanding of the relationship between time, treatment of cracks using crack fill materials, and the potential interaction with MgCl. The null hypotheses are 1) there is no overall difference between crack fill products A & B; 2) there is no difference between products exposed and not exposed to MgCl; and, 3) there is no interaction between crack fill products and MgCl.

Experiment Location
Two sites in Colorado, USA were designated to evaluate crack sealant performance. The designated test locations are on State Highway 66 (SH66) east of Lyons, Colorado and State Highway 7 (SH7) south of Estes Park, Colorado. Although both locations have similar traffic patterns and are maintained by the Colorado Department of Transportation (CDOT) Region 4 maintenance department, the locations differ in elevation. SH66 in Lyons, Colorado is located in the foothills at the base of the Rocky Mountains at an elevation of 1635 meters (5364 feet). SH7 in Estes Park is located near the continental divide in the Rocky Mountains at an elevation of 2294 meters (7526 feet).

Experiment Methods
CDOT Region 4 maintenance department evaluated and identified the test areas and filled cracks with product A and product B in May, 2005. At the Lyons site, a total of 60 cracks were identified, 48 were treated with crack fill products and 12 were left untreated. Crack filling at the Lyons test section was conducted systematically starting on May 4, 2005. Of the 60 cracks, there were 10 sections consisting of six cracks in a row. Of the 10 sections, four had product A crack fill and four had product B, and two did not have any crack fill at all. Further, of the ten sections, sections one through five had MgCl sprayed into the crack prior to crack filling. Similarly, crack filling was conducted systematically at the Estes Park test section on May 5, 2005. Of the 96 cracks identified, 48 were treated with crack fill and 48 were left untreated. Of the 96 cracks, there were eight sections consisting of 12 cracks in a row. For four of the eight sections, crack fill product B and control sections where no crack fill was applied were alternatively used. For the other four sections, crack fill product A and no crack fill were alternatively used. Of the eight sections, four had MgCl sprayed into the crack prior to crack filling.
Prior to crack filling, compressed air was used to blow out debris from each crack. Specific cracks were sprayed with MgCl deicing solution. CDOT maintenance workers filled each crack with the appropriate crack fill product using a spray wand applicator. After crack filling was complete, cracks were considered to have 100%