PARES—An Expert System for Preliminary Flexible Pavement Rehabilitation Design

TIMOTHY ROSS, STEPHEN VERZI, SCOTT SHULER, GORDON MCKEEN, AND VERNON SCHAEFER

The development of a knowledged-based expert system to assist the New Mexico State Highway and Transportation Department in the evaluation and design of rehabilitation schemes for flexible pavements is described. The system uses information provided by users to establish preliminary rehabilitation schemes that would be reasonable and cost-effective. A cost-estimate module for ranking the rehabilitation schemes according to relative cost is integrated into the system. The need for such a system in New Mexico and the knowledge base used to construct the IF-THEN-ELSE type rules in the expert system are described, and the distress conditions addressed and the rehabilitation strategies considered are discussed. The system is rich in the sense that it also distinguishes among distress situations requiring routine maintenance as opposed to rehabilitation requiring more extensive construction efforts. An example session using the expert system is provided.

The selection of pavement rehabilitation alternatives depends on distress type present in the pavement, ride quality, traffic volume, structural section, maintenance history, and other factors. Although the manual process of determining rehabilitation schemes has been effective, a computerized knowledge-based expert system would allow a more detailed preliminary estimation of rehabilitation needs such that costs could be better ascertained. This would contribute to a more accurate identification of the number and extent of projects to be scheduled for rehabilitation.

Such an expert system could also be used to reduce the time required for new personnel to develop an adequate level of on-the-job experience. More experienced personnel may use the expert systems to make their own designs a more expeditious and economical process. The expert system for preliminary rehabilitation design will immediately benefit the New Mexico State Highway and Transportation Department (NMSHTD) by providing assistance to personnel responsible for estimating initial costs of rehabilitation projects with expert guidance regarding the most cost-effective alternatives using available information. The expert system could be queried by users for details on the construction or rehabilitation problem of concern, with the output used to identify potential problems and offer alternative solutions for obtaining the best pavement rehabilitation scheme for a given situation.

This paper summarizes a recent New Mexico study (*1*) to develop a PAvement Rehabilitation Expert System (PARES) for the preliminary rehabilitation design of New Mexico flexible pavements. Good reviews of expert system technology in transportation and other civil engineering disciplines are available in the literature (*2*). The paper presents some relevant previous efforts on the application of expert systems technology in highway pavement management, discusses the current practices in the state of New Mexico, addresses the particular features and utility of the PARES code for use in flexible pavement rehabilitation, and concludes with an example application of the system.

RELATED EXPERT SYSTEMS FOR HIGHWAY PAVEMENTS

An expert system originally developed for the Washington State Highway system by Ritchie et al. involves the area of flexible pavement rehabilitation using a code called SCEPTRE (*3*). The SCEPTRE code is used to provide a user with several rehabilitation strategies based on the existing condition of a roadway and the user-specified service life of the desired rehabilitated pavement. SCEPTRE is based on "IF-THEN" type rules and uses a backward-chaining inference method (reasoning goes back from known facts to a hypothesis).

Haas and his colleagues (*4–6*) have developed expert systems for flexible pavement management, pavement distress analysis, and pavement condition data inventory. One of these systems, PRESERVER (*4*), assists field engineers and supervisors in analyzing pavement distress data and proposes routine maintenance strategies. This system is similar to SCEPTRE, except that it proposes maintenance rather than rehabilitation strategies.

In other developments, Hall et al. (*7*) have developed an expert system, called EXPEAR, to assist the design engineer in the evaluation and preliminary rehabilitation design for jointed reinforced, jointed plain, and continuously reinforced concrete pavement (JRCP, JPCP, and CRCP). EXPEAR uses information provided by pavement engineers to determine the type and cause of distress so that an appropriate rehabilitation strategy can be selected.

T. Ross, Department of Civil Engineering, and S. Verzi, Department of Computer Science, University of New Mexico. Albuquerque, N.Mex. 87131. S. Shuler, Asphalt Institute, Box 14052, Lexington, Ky. 40512. G. McKeen, New Mexico Engineering Research Institute, Box 25, Albuquerque, N.Mex. 87131. V. Schaefer, Department of Civil Engineering, South Dakota State University, Brookings, S.Dak.

Aougab et al. (*8*) have developed an expert system, PAMEX, for maintenance management of flexible pavements. Ritchie (*9*) has developed an expert system, termed OVERDRIVE, to assist local engineers in designing the structural thickness of asphalt concrete overlays. Haas and Shen (*4,6*) have developed PRESERVER, an expert system for the Canadian province of Ontario to help field engineers and supervisors analyze pavement distress information to propose routine maintenance strategies. Hajek et al. (*10*) have developed ROSE, an expert system for recommending routing and sealing of asphalt concrete pavements in cold areas of Canada. Tandon and Sinha (*11*) have developed an expert system to estimate highway pavement routine maintenance needs and expected costs at the subdistrict level. And finally, to underscore the growing emphasis and importance of expert systems in pavement management, Barnett et al. (*12*) have published a Federal Highway Administration report that provides guidelines to the states for the development and distribution of highway-related expert systems.

NEW MEXICO PAVEMENT REHABILITATION SYSTEM

Performance of each of 3,000 evaluation sections in the New Mexico pavement network is documented periodically through visual condition surveys and roughness measurements. Rehabilitation procedures for flexible pavements in New Mexico are intended to provide 10 years service with routine maintenance; however, the routine maintenance required during this interval will vary depending on the rehabilitation method selected. The repair strategies vary in effectiveness, cost, and intended purpose.

The current New Mexico pavement management system consists of a very detailed description of the roadway to be evaluated. Information collected from the field is transferred to a computer system to present the user with seven types of inquiries regarding the roadway segment: (*a*) pavement data, (*b*) condition data, (*c*) planned projects, (*d*) project history, (*e*) traffic data, (*f*) road safety data, and (*g*) distress detail. In New Mexico distress is quantified on the basis of American Public Works Association (APWA) guidelines (*13*).

A priority ranking system based on field condition surveys and traffic volume has been developed by NMSHTD to assess which of the sections should be rehabilitated or reconstructed. This system has been developed such that a priority assignment indicates that rehabilitation is necessary. Therefore, pavements requiring routine maintenance theoretically would not receive a priority value and therefore would not be considered for rehabilitation. An exception to this might include pavements with escalating maintenance costs, which a particular highway district judges as requiring more than routine treatment.

After the priority assignments are made an initial estimate of cost for rehabilitation is made. The preliminary cost estimate is used to determine the number and extent of projects to be considered for rehabilitation depending on the funds available. After the projects to be rehabilitated are identified, a more comprehensive preliminary design is initiated. This design is based on a visual survey by the design engineers, results of the condition survey and roughness data, construction history, and other data, if available. Rehabilitation alternatives are compared on the basis of initial and long-term cost-effectiveness for a design period of 10 years.

Although the manual system in New Mexico was effective in determining appropriate rehabilitation alternatives, an expert system will be advantageous in the assessment of initial rehabilitation costs for at least two reasons. First, the initial cost estimate for prioritized projects would be significantly more accurate. Second, much of the iterative process involved with comparing the preliminary design with initial estimates made by planning personnel would be reduced because the initial estimate involves the same reasoning that is included in the preliminary design procedure.

THE EXPERT SYSTEM—PARES

PARES was implemented in EXSYS Professional (*14*), a commercially available expert system shell. EXSYS has been used extensively in other applications (*15*). EXSYS allows for both backward-chaining (goal driven) and forward-chaining (data driven) inferencing. The IF-THEN-ELSE structure is the general form of the rules of an EXSYS knowledge base. This structure is used for the rule base irrespective of whether the rule is chained in a forward or backward manner. All portions of the IF clause must be satisfied before the conclusion (THEN clause) of a rule is activated. If a single portion of the IF clause is disproved, the ELSE portion is activated.

THE INFERENCING SYSTEM—EXSYS

Each of the conditions in the IF portion of a rule is specified by a Boolean-valued formula that will evaluate to either true or false. The formula can be composed of mathematical variables in a logical relation ($<$, $>$, $=$, etc.) or propositional variables in a predicate calculus relation. When all IF conditions have a truth assignment, the rule can be invoked, and either the actions of the THEN portion or the ELSE portion are carried out. Actions in the THEN or ELSE portions of the rule can perform many different functions, such as execution of external programs (e.g., the PARES cost module), manipulation of mathematical variables (e.g., calculation of mill depths and overlay thickness), setting of conditions for the IF portions of other rules, and selection of final rehabilitation strategies. In EXSYS the ELSE portion of the rule is optional.

In a forward-chaining inference, an existing knowledge base is used to invoke as many rules as possible, where the actions from these rules are used as the conditions for new rules and the invocation proceeds forward until no more rules can be invoked. Backward chaining proceeds by selecting a rule in which it is desired to have one or more of the actions executed in the THEN portion of the rule (goal). For the action to take place, all of the conditions in the IF portion of the rule must be satisfied (i.e., evaluated to be true). Backward chaining proceeds in a "depth-first" manner through the rule base, searching the rule base for rules whose actions will enable the firing of rules that have already been considered in the chain of rules.

DEVELOPMENT OF THE KNOWLEDGE BASE

The PARES knowledge base was developed from procedures documented in New Mexico state highway agency manuals, some AASHTO procedures, and a group of NMSHTD pavement rehabilitation experts. The state highway experts provided the heuristic rules used to formulate the knowledge base. The experts were particularly important to this work, but the input from different individuals invariably resulted in some conflicts of opinion. The resolution of these differences was addressed by the research team in selecting among the available alternatives.

The first step in the development of the knowledge base was to construct a list of the data to be entered by the users into the expert system. Rehabilitation of roadway surfaces is necessitated by the existence of certain types and levels of distress. The development of the PARES code used standard distress types as documented in the APWA *Pavement Condition Index for Asphalt Pavements* (*13*). The expert system PARES considers 23 types of distress and 3 levels of distress severity for each distress type. The distresses and levels are given in Table 1.

The expert system also considers the extent and the severity of each distress type. For most distresses, the extent is entered in terms of the percentage of the road covered by the particular distress severity. For longitudinal cracking and transverse cracking the extent is entered as the number of lineal feet of cracks per project. For depressions at bridges and railroad crossings, the extent is the number of these distresses of a particular severity present in the project. These two are inherently localized distresses and, as such, can be treated separately from the rest of the distresses.

The second step in representing the asphalt pavement rehabilitation knowledge was the creation of hierarchical structures (a logic tree). The logic tree forms the shell in which knowledge-based rules stating the declarative and procedural knowledge are inferenced.

Interviews were conducted with five expert New Mexico pavement designers. From these interviews, a multilevel logic tree was conceived to capture the generality of possible distress conditions. This logic tree attempts to structure the knowledge of the experts that typically is not reducible to algorithmic form. Both the distresses and plausible rehabilitation strategies were classed into special categories that would be useful in relating the distresses to the rehabilitation strategies. The research team acted as additional experts to develop categorizations of distresses and rehabilitation strategies as well as the logic to tie those together into a multilevel logic tree. The experts decided that 21 rehabilitation strategies (given in Table 2) captured the experience in the past of rehabilitations to New Mexico road surfaces and, to a lesser extent, plausible strategies not frequently used in New Mexico. The multilevel logic tree relating the distress situations to the potential rehabilitation strategies is shown in Figure 1, where the encircled numbers represent the strategies given in Table 2.

To categorize the pavement distresses, the research team classified the possible distresses into five distress type sets. Some of these sets may be empty for a particular design situation, indicating that no distresses in that category have been seen on the existing pavement surface. These five distress categories are general maintenance distresses, localized maintenance distresses, surface-mix distresses (due to the asphaltic material), surface cracking distresses, and subgrade (subsurface) distresses. When all known distresses have been specified by the user, PARES inferences on the rule base to provide possible rehabilitation strategies to the user.

SPECIFICS OF THE RULE BASE IN PARES

There are 278 rules in the PARES rule base. These rules, in conjunction with the geometric information about the roadway surface provided by the user, compose the knowledge base for a particular application of the PARES code. Roadway length and width (without shoulders) are the only geometrics used in PARES. Rules 1 to 73 in the PARES rule base embody the logic used to segregate all the input data and the distress conditions provided by the user into the five general distress type sets. Each time a distress type set is confirmed in a rule a counter is incremented so that PARES can use the number of distresses in a particular distress type set in logic deeper in the logic tree. Rules 1–73 are inferenced

TABLE 1 Distress Types and Severity Levels for PARES

Distress Types	
Alligator (fatigue) Cracking	Patch Deterioration
Bleeding (flushing)	Polished Aggregate
Block Cracking	Potholes
Bumps and Sags	Pumping and Bleeding
Corrugation	Railroad Crossings
Depressions	Raveling and Weathering
Depressions at Bridges	Rutting
Edge/Center-line Cracking	Shoving
Joint Reflection Cracking	Slippage Cracking
Lane/Shoulder Drop-off	Swelling
Lane/Shoulder Separation	Transverse Cracking
Longitudinal Cracking	

Distress Severity Levels
Low Severity
Moderate Severity
High Severity

TABLE 2 Rehabilitation Strategies

1. Do nothing
2. Crack seal
3. Chip seal
4. Asphalt Overlay
5. Crack seal + overlay
6. Asphalt rubber interlayer + overlay
7. Geotextile fabric strip + overlay
8. Geotextile fabric sheet + overlay
9. Cold in situ recycling + chip seal
10. Cold in situ recycling + overlay
11. Hot recycling + chip seal
12. Hot recycling + overlay
13. Heater scarification + overlay
14. Cold milling + overlay
15. Cold milling + interlayer + overlay
16. Cold milling + cold in situ recycling + overlay
17. Pulverization + overlay
18. Portland Cement Concrete
19. Reconstruction
20. Dig out and patch
21. Patch surface

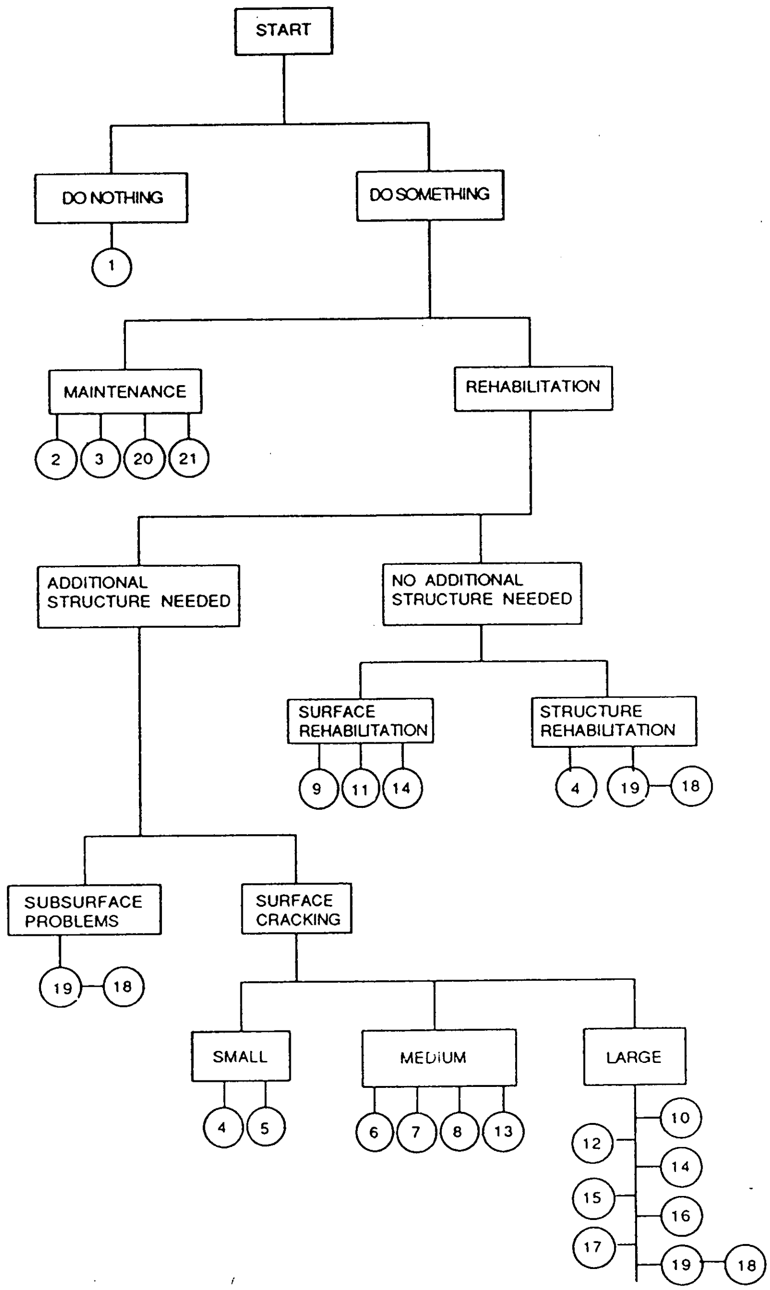

FIGURE 1 Multilevel logic tree for PARES.

in a forward-chaining manner since classification is inherently a data-driven task. In PARES, the main body of rules (Rules 74–249) are inferenced in a backward-chaining mode, where the output consists of rehabilitation strategies for roadway repair for the current input situation. Finally, Rules 250–278 are inferenced using a forward-chaining mode, since these rules calculate specific values for mill depth and overlay thickness for the rehabilitation strategies chosen in Rules 74–249. Examples of the first 73 rules follow:

RULE NUMBER: 1
IF distress type set contains alligator cracking
AND the alligator cracking is type C.
THEN localized distress set contains alligator cracking
AND increment localized distress set counter by 1.
(Note: as described later, PARES will query the user about the "type" of alligator cracking present.)

RULE NUMBER: 28
IF distress type set contains lane/shoulder drop-off
AND lane/shoulder drop-off severity is low
AND the extent of lane/shoulder drop-off is greater than 10 percent,
THEN subsurface distress set contains lane/shoulder drop-off
AND increment subsurface distress set counter by 1.

RULE NUMBER: 72
IF distress type set contains alligator cracking
AND the alligator cracking is Type A OR Type B
AND distress type set contains rutting
AND rutting severity is moderate OR high
THEN subsurface distress set contains alligator cracking AND rutting
AND the rutting is Type B (surface mix material failure)
AND increment subsurface distress set counter by 1.

The categorization of rehabilitation strategies was accomplished at different levels within the logic tree. At each major branch point in the logic tree in Figure 1, decisions have to be made on the basis of available evidence provided by the user. It is instructive to list here some of the rules that affect some of these decisions. For example, there is the strategy of do nothing, which is an "escape route" strategy for the expert system when no distresses are entered by the user. If PARES receives no distress types, it must assume that no rehabilitation is required. The rule governing this escape is

RULE NUMBER: 74
IF all distress type sets contain nothing,
THEN do nothing.

To decide whether a distress is maintenance only or rehabilitation, a typical decision rule is

RULE NUMBER: 82
IF subsurface distress set contains nothing
AND surface cracking set contains nothing
AND surface mix distress set contains nothing
AND average daily traffic is less than 5,000
AND total extent of maintenance distresses present is less than 50 percent,
THEN the type of strategy needed is maintenance only.

The difference between a maintenance strategy and a rehabilitation strategy is not clear in many repair situations. Although it is easy to determine that railroad crossings and bridge depressions can almost always be addressed with maintenance strategies, other distress types that are typically nonlocal phenomena may not be easily categorized as maintenance problems. Generally local distress types such as bumps and sags, corrugation, depressions, patch deterioration, and potholes are usually found in low extent, and so can be handled using maintenance strategies. However, if these same types of distress are apparent over a significant extent of the project surface and the average daily traffic is high enough, the pavement would tend to require rehabilitation. For simplicity, it was decided that when a generally nonlocal distress type occurs with generally local distress types, if the local distresses occurred in low severity, they could be handled by maintenance strategies. But, if the extent of local distresses becomes too high and if the average daily traffic is too high, rehabilitation would be required rather than maintenance. The numerical thresholds for this transition are shown in Figure 2.

In PARES there are four maintenance strategies (Rehabilitation Strategies 2, 3, 20, and 21 in Table 2) that can be recommended if the distress conditions are not sufficient to warrant new construction, or these same four maintenance strategies may be recommended by PARES as "additional construction" (see typical example later) if they are associated with recommended rehabilitation strategies as explained above. These maintenance strategies are also considered escape routes from PARES, since the primary purpose of PARES is rehabilitation. Typical maintenance rules follow:

RULE NUMBER: 84
IF the type of strategy needed is maintenance only
OR maintenance with rehabilitation
AND maintenance distress set contains edge/centerline cracking
THEN crack seal.

RULE NUMBER: 91
IF the type of strategy needed is maintenance only
OR maintenance with rehabilitation
AND localized distress set contains alligator cracking
THEN dig out and patch.

Whether additional pavement strength is needed is determined by the difference between the required new pavement structural number (SN_{new}) and the existing structural number (SN_{old}). If SN_{new} minus SN_{old} is greater than 0.30, an overlay, or recycled pavement, is recommended because additional strength is necessary. In PARES the new SN_{new} is calculated using the 1972 AASHTO guide (*16*) and SN_{old} is provided by the user. The choice between strategies that rehabilitate the

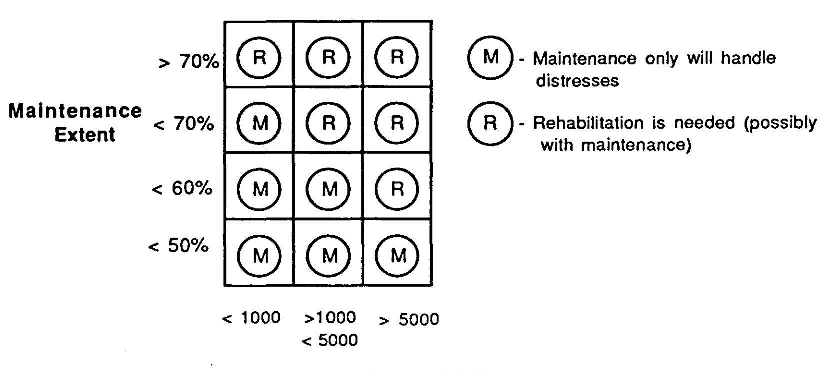

FIGURE 2 Transition zones between maintenance and rehabilitation.

pavement surface only and strategies that rehabilitate both the subgrade and the surface is made on the basis of whether a subsurface distress condition is present.

If a subsurface distress condition is present (e.g., swelling, Type B alligator cracking, or Type A rutting) in significant extent, then a rehabilitation strategy that treats the subgrade would be recommended. There are exceptions (such as if the moisture condition of the pavement is stable) to such a recommendation, but the general rule is that a rehabilitation strategy resulting from a subsurface distress will override rehabilitation strategies resulting from other types of distress conditions, giving rise to rules of the following form:

RULE NUMBER: 110
IF the type of strategy needed is rehabilitation
AND structural strength of the existing road is not adequate for future design
AND subsurface distress set contains swelling,
THEN remove and replace with asphalt (reconstruction).

Some rehabilitation strategies are used when no additional strength is needed (i.e., either to improve the surface course or to improve the subsurface as well as the surface). A rule to determine whether an increase in the structure of the road is necessary is

RULE NUMBER: 102
IF $(SN_{new} - SN_{old}) > 0.3$
THEN structural strength of the existing road is not adequate for future design
ELSE structural strength of the existing road is adequate for future design.

If no additional strength is required, PARES determines whether improvements to the asphalt concrete are required through either recycling material or reconstruction. An example of a rule in this situation is (note: rehabilitation strategies are conclusions at this point)

RULE NUMBER: 238
IF the type of strategy needed is rehabilitation
AND structural strength of the existing road is adequate for future use
AND surface mix distress set contains bleeding
THEN hot recycle + chip seal
OR cold mill + overlay.

If additional strength on the roadway surface is required, PARES determines whether the rehabilitation should be based on subsurface problems or surface cracking problems. The decision whether additional strength rehabilitation is due to subsurface or cracking problems is given in the following rule:

RULE NUMBER: 111
IF the type of strategy needed is rehabilitation
AND structural strength of the existing road is not adequate for future design
AND subsurface distress set contains nothing,
THEN the surface cracking matrices should be used,
ELSE the surface cracking matrices should not be used.

The surface cracking matrices mentioned in this rule embody the knowledge from experts used to assess issues associated with surface cracking problems. The surface cracking problems are addressed by a variety of rehabilitation strategies, depending on the severity of the cracking and the number of cracking-related distresses.

In PARES, the surface cracking rehabilitation strategies are divided into three categories (see Figure 1): small (cracking is not a problem), medium (cracking could be handled with an interlayer), and large (cracking should be eliminated), which are the output from the second matrix shown in Figure 3 (S, M, or L). A choice among the three categories is made through the use of the surface cracking matrices in Figure 3. There are two surface cracking matrices. The first matrix shown in Figure 3 is designed to be used with each nonmaintenance, nonsubsurface distress type, where a repair level (L, M, S) is determined on the basis of severity (low, medium, high) and extent (in percentage, 0–100) of the distress type in question. In other words, the first matrix addresses the different types of cracking that can happen (e.g., alligator cracking, transverse cracking, etc.), and it also addresses those distresses that can appear along with the cracking (e.g., raveling, rutting, etc.). The second matrix in Figure 3 is designed to take the repair level outputs from the first matrix (S, M, L) and produce an overall repair level (S, M, or L corresponding to small, medium, and large), which is then used in the rule base to choose among the three categories of strategies. The interface code used at the beginning of the expert system to get pertinent information from the user uses arrays for keeping track of the distresses and calculates the necessary overlay depth. Typical rules for surface cracking repair strategies follow:

RULE NUMBER: 112
IF the surface cracking matrices should be used
AND distress type set contains alligator cracking
AND alligator cracking (fatigue Type A) severity is low
AND extent of alligator cracking is less than 10 percent,
THEN repair level is small.
(Note: in this rule PARES would query the user about the type of alligator cracking.)

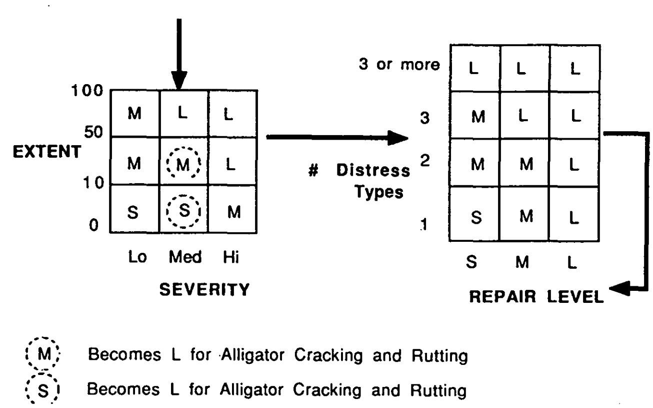

FIGURE 3 Surface cracking matrices developed in the knowledge base.

RULE NUMBER: 139
IF the surface cracking matrices should be used
AND distress type set contains edge/centerline cracking
AND edge/centerline cracking severity is moderate
AND extent of edge/centerline cracking is between 10 and 50 percent,
THEN repair level is medium.

Finally, when PARES is at the level of abstraction below "surface cracking" in the logic tree (at the numbered circles in Figure 1), its rule base recommends rehabilitation strategies. Typical recommendation rules follow:

RULE NUMBER: 210
IF existing cracking should be addressed with an interlayer
AND surface cracking set contains alligator cracking,
THEN asphalt rubber interlayer + overlay
OR geotextile fabric sheet + overlay
OR heater scarification + overlay.

RULE NUMBER: 224
IF existing cracking should be destroyed
AND surface cracking set contains alligator cracking,
THEN cold in situ recycle + overlay
OR hot recycle + overlay
OR cold mill + overlay
OR pulverization + overlay
OR remove and replace with asphalt (reconstruction).

RULE NUMBER: 237
IF existing cracking should be destroyed
AND distress type set contains swelling
AND the moisture condition of the pavement is stable,
THEN cold mill + overlay.
(Note: if this rule is invoked, PARES will query the user about the moisture condition of the road.)

Another escape route designed into PARES is the situation requiring a rigid pavement rehabilitation scheme. Since PARES is an expert system for flexible pavements, it treats a situation requiring a concrete pavement as a special situation. The following rule governs in this situation:

RULE NUMBER: 254
IF reconstruction is a recommended rehabilitation strategy
AND the average daily traffic exceeds 30,000
AND the expected design life desired is greater than 10 years
AND the time since the last repair on this road is less than 10 years,
THEN go concrete.
(Note: if this rule is invoked, PARES will query the user about the time since last repair.)

PARES even has logic built into it to avoid overlapping repair strategies. An example of this logic is the following rule:

RULE NUMBER: 252
IF crack seal
AND overlay
AND overlay + crack seal, all are recommended strategies,
THEN crack seal + overlay will cover all the situations.

ADDITIONAL FEATURES OF THE KNOWLEDGE BASE

If the user specifies that alligator cracking is one or more of the distresses, PARES will ask the user to specify the type of alligator cracking present and to determine whether the distress is primarily related to surface or subgrade problems. PARES asks the user this question whenever the first rule involving alligator cracking is addressed in the inferencing process. A typical question would be the following:

The alligator cracking is (choose one or more of the following)

1. Type A [alligator cracking in the surface only (i.e., due to loading fatigue)]
2. Type B (alligator cracking as a result of a subgrade problem)
3. Type C [localized alligator cracking (i.e., low extent in a small portion of the roadway surface)].

PARES can also query the user as to the type of rutting, if rutting is a distress indicated by the user. More information on rutting is available from Pavlovich et al. (*17*). A typical question is

The rutting is (choose one or more of the following)

1. Type A (indicates a subgrade problem)
2. Type B (indicates a surface mix material problem).

Both of the preceding user questions involve visual inspection of the road surface, and the user is assisted in PARES with a schematic illustrating Type A and B rutting.

To assist in determining milling depth, if milling is necessary, or to determine the amount of crack seal to apply, if crack seal is necessary, PARES will query the user about the depth of surface cracking. A typical question is

The depth of cracking is known to be ___ (inches) (user fills in the blank).

An additional feature in PARES is that it has the capability to calculate mill depths and overlay depths for specific rehabilitation strategies used in New Mexico; hence it is a design tool. If the user has provided PARES with surface cracking depths, these values are used for the milling depths. If the user does not know these values, PARES estimates the depths on the basis of the level of severity of the cracking (e.g., low severity implies mill depth = 1 in., medium severity implies mill depth = 2.5 in., etc.). The layer (structural) coefficient (SC) for the old pavement is input by the user (see example later), and this value, along with the difference between SN_{new} and SN_{old}, is used to determine the new overlay thickness, if required. In PARES, new or recycled asphalt material carries an SC of 0.4, and existing pavement carries a value for SC between 0.1 and 0.4 depending on user judgment.

OPERATION OF THE PARES CODE

Complete details of the physical operation of the PARES code are addressed elsewhere (*1*). A single screen data entry interface (see Figure 4a) minimizes the user's interaction with EXSYS. Built-in error checking is accomplished on the information entered by the user. The interface also contains an explanation window, which is designed to be helpful to the user in terms of additional on-line help to explain what is to be entered in each field (or section) for the infrequent user. In PARES a cost module was implemented to rank rehabilitation strategies. The costs estimated are for construction of the roadway surface only. The cost module was designed to be interactive with the user and to have considerable flexibility. The user can use a default unit cost file, call his own unit cost file, or change unit costs during run time in a PARES session.

TYPICAL EXAMPLE OF A PARES SESSION

A typical session of the PARES code is shown in Figure 4. This session was compared with an actual rehabilitation test job done in New Mexico in early 1988 near Cimarron. Figure 4a shows the input for a pavement segment 0.2 mi in length,

(a)

Number of Lanes: 2	Roadway Length: 0.20 miles
Roadway width: 24 feet	Regional Factor: 1.5
Design Life: 10 years	ESAL: 2920000
SC for old AC: 0.2	Serviceability Index: 2.0
Estimated R-Value: 45	Existing SN: 1.8

DISTRESSES

Type	Severity	Extent
Transverse Cracking	Low	1000 feet
Transverse Cracking	Medium	300 feet
Alligator Cracking	Low	15%
Alligator Cracking	Medium	5%
Longitudinal Cracking	Medium	300 feet

Calculated future SN: 3.068 Exit (Y/N)?:

EXPLANATIONS

.....this window provides the user with explanations and instructions for any of the fields in which the computer cursor is awaiting data entry......

(b)

Rehabilitation Strategies	Cost ($)
Cold insitu recycling 2.5 inches + overlay 1.75 inches	13,636
Hot recycling 2.5 inches + overlay 1.75 inches	13,693
Cold mill 2.5 inches + overlay 4.25 inches	26,660
Cold mill 2.5 inches + interlayer + overlay 4.25 inches	33,700
*Pulverization + overlay	59,523
*Reconstruction - remove and replace asphalt	69,661

Additional Construction	Cost ($)
Dig out + patch (These are supplemental maintenance strategies)	5,333

* This strategy includes an estimated overlay pavement depth

FIGURE 4 (*a*) Typical input screen and (*b*) typical results screen with cost ranking in PARES.

with a layer coefficient (SC) of 0.2 for the existing surface and other parameters as shown. The user specifies the input that is known (PARES can run with incomplete input data). Such quantities as the equivalent single-axle load (ESAL) and the required new structural number, SN_{new}, are calculated from information provided by the user (see Figure 4a). The rules used within a typical PARES session are a function of the distress information provided by the user. Recommended rehabilitation strategies ranked according to cost of the constructed surface (exclusive of shoulders) are shown in Figure 4b.

In this example, six strategies are recommended with the top two being very competitive in cost according to New Mexico practice. To illustrate how PARES selects various rehabilitation strategies, the inferencing involved in the first strategy, cold in situ recycling 2.5 in. + overlay 1.75 in., will be described. Only a few of the rules listed in this example session of PARES appear in this paper.

Since in this example alligator cracking was provided twice by the user as two of the distress conditions, PARES queries the user as to the types of alligator cracking; the user answers "Types A and C." PARES uses this information to invoke rules 2, 34, and 69 to classify the distress into surface cracking, and it counts three surface cracking distress conditions. Then it invokes rules 76 and 77 to infer that rehabilitation is needed, not maintenance alone (see Figure 1). PARES invokes Rule 102 to determine that the existing strength of the pavement is inadequate and that the pavement needs more strength. Rule 111 then determines that the surface cracking matrices (Figure 3) should be used to estimate the needed repair level. Rules 113, 148, and 190 are then invoked for alligator cracking, longitudinal cracking, and transverse cracking, respectively, to determine that a medium repair level is needed. Rule 198 uses the results of the recommended repair level and the fact that three surface cracking conditions exist to determine that destruction of the existing cracks is necessary before any new overlay. Finally, Rules 224, 228, and 229 use these results and conduct simple calculations to recommend that the rehabilitation strategy should first cold in situ recycle 2.5 in. of the old pavement structure (this repairs the existing cracks), then add 1.75 in. of new overlay (this reinforces the pavement structure to the recommended strength).

CONCLUSIONS

An expert system for preliminary pavement rehabilitation design for flexible pavements in New Mexico has been described. Its implementation when compared with an actual New Mexico rehabilitation project is illustrated. The rehabilitation strategy used on the actual project was one of the recommended strategies developed by PARES. The system currently is in use in New Mexico and has been shown to be both a rapid initial estimator of rehabilitation job costs and a tool for new engineers to understand and learn current procedures used by expert designers.

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