Use of Expert Systems in Managing Pavement Maintenance in Egypt

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An attempt to apply expert systems to management of pavement maintenance in developing countries is presented. The development of this system is based, however, on data from Egypt. A twofold system has been developed to assist highway agencies that lack in-house experts in evaluation of asphalt pavements and assessment of maintenance and rehabilitation needs. The evaluation subsystem is an interactive algorithmic computer program, the output of which is an index-type rating of pavement condition—namely, the pavement condition index—calculated from distress data obtained from visual condition surveys. The maintenance and rehabilitation subsystem is an expert system that simulates a consultation between the engineer and an expert in the field of pavement maintenance. This expert system can be run as a stand-alone program with input data supplied by the user engineer, or it can be called from inside the environment of the algorithmic program to analyze its data base. The system has been developed and verified using data from portions of the Egyptian road network where comprehensive visual inspection data are available.

Most in-service pavements were built years ago; few new pavements are being constructed now. A high percentage of the total network mileage has deteriorated to conditions considered a functional failure, not performing the intended function of serving users safely and comfortably and instead damaging vehicles, slowing travel, increasing fuel consumption, and sometimes causing a hazardous ride.

A deteriorated pavement network needs localized repairs (e.g., crack sealing, pothole filling) and extended rehabilitation of entire pavement sections. Unfortunately, maintenance and rehabilitation (M&R) funds can not keep pace with M&R requirements; thus, there is a need for standard, practical decision-making procedures that can be applied to define what, where, and when M&R work should be done (*1*).

In developing countries—Egypt, for instance—highway agencies suffer (a) low M&R budget, and (b) the absence of an efficient system for managing the investments in pavements. This normally yields a random application of the limited funds to fill the most extreme needs for repair. The remaining budget proves inadequate to serve the total area involved, and the assumed recurrent maintenance suffers or, in most cases, is omitted altogether. The subsequent budget period usually shows that the pavement has deteriorated more rapidly than expected because of lack of maintenance, so more of the small budget is required for heavy remedial work, and the downward cycle of deterioration continues.

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Many components of pavement maintenance management are complex and poorly structured, making algorithmic computations difficult (*2*). Pavement maintenance management requires the knowledge and expertise of experienced pavement engineers. Artificial intelligence (AI), a relatively new computer application and programming technology, and expert systems, a subset of AI (*3,4*), provide efficient and effective tools for handling expertise and decision logics. Thus, expert systems have great potential for addressing pavement maintenance needs (*5–13*). An expert system can systematically formalize and use the thought process and experience of experts as well as incorporate algorithmic computations when appropriate.

The selection and scheduling of M&R activities to a diversity of roadway section types, conditions, traffic characteristics, and such are repeated tasks in any highway agency that can benefit from the rule-based logic of an expert system, because these assignments are not made on the basis of exact engineering criteria. This is particularly true in developing countries, where such systems can play an important role in offsetting the lack of experience.

SYSTEM DESCRIPTION

This work effort aims at developing a simplified pavement condition evaluation system that uses microcomputer technology and that allows the user to select the most appropriate maintenance or rehabilitation action needed for upgrading pavement condition via an expert system consultation.

The system consists of two programs. The first is an algorithmic program that allows for the recording of pavement surface distress information, handles pavement condition index (PCI) calculations, and acquires data on the applicability of a variety of maintenance and rehabilitation activities and their unit costs and projected service lives. This program manages data input, storage, and retrieval. It also generates condition reports that can be used by the second program. The collection of distress data and the calculations required to convert them to a condition index are based on the PCI procedure, in which the network under consideration is divided into a set of branches (e.g., major streets), each of which is further divided into homogeneous sections (e.g., street blocks). Finally, each section is divided into several sample units. A random sample is selected from these sample units, and a detailed visual inspection is performed. The details of the procedure are available elsewhere (*14*).

The second program is an expert system that determines and ranks the maintenance and rehabilitation actions to be taken, on the basis of the data passed to it either manually by the user or automatically by the first algorithmic program. This expert system program is easy to use and is readily adaptable to allow for the incorporation of new required rules or changes in the existing ones. EXSYS Shell (*15*) was used to develop this program.

Developing the system to take the form of two programs captures the advantages and power of the two programming techniques. The algorithmic program carries the burden of the immense amount of computations; the expert system program suits the symbolic and heuristic nature of human expertise. The system has been developed and verified using data from portions of the Egyptian road network where comprehensive visual inspection data is available (*16*).

Algorithmic Program

Input

As a simple data manager, the program accepts new data or shows previously stored data upon a user's request. Figure 1 shows the first screen, in which the computer asks for the user's selection.

The program then responds (Figure 2), inquiring about branch or link code, which is a set of alphanumeric characters that facilitates reference to the link. It also asks for section code and its area and for sample unit number and its area. Typographical errors can be corrected upon the user's request.

The next phase is the input of distress data. The user supplies the data from condition surveys at random, and the program accumulates and arranges these data. Figure 3 shows distress types considered, the units in which they are measured, and the input process of existing distress types.

PCI CALCULATIONS

New Data .... [1]

Already Existing Data .... [2]

Note

Select [1] if you want to add new distress data or replace existing data of a specific sample unit.
Select [2] if you want to see what's inside.

FIGURE 1 New input or move to data base.

PCI CALCULATIONS

1- Link code : shehab

2- Section Code : test24
3- Section Area [sq. meter] : 500

4- Sample Unit No. [1-999] : 30
5- Sample Unit Area [sq. meter] : 100

ENTER C TO CHANGE OR ANY OTHER KEY TO PROCEED :

FIGURE 2 Identification data.

DISTRESS TYPES

1. Alligator Cracking	*10. Long & Trans Cracking
2. Bleeding	11. Patching & Utility Cuts
3. Block Cracking	12. Polished Aggregate
*4. Bumps & Sags	*13. Potholes
5. Corrugation	14. Railroad Crossing
6. Depression	15. Rutting
*7. Edge Cracking	16. Shoving
*8. Joint Reflection cracking	17. Slippage Cracking
*9. Lane / Shoulder Drop off	18. Swell
	19. Weathering and Raveling

All distresses are measured in sq. feet or sq meters [according to the previously specified system] except distresses 4,7,8,9 and 10 which are measured in linear foot or meter. Distress 13 is number of potholes.

EXISTING DISTRESS TYPES

Choose Distress Type by Number [1 to 19] : 1
Severity : Low [1] Medium [2] High [3] : 2
Amount of Distress : 6

Enter E to End or any other key for another distress type :

FIGURE 3 Input of existing distress types.

Output

Data summaries appear as follows: (a) the density matrix, which includes the density of each distress type–severity combination, that is, the amount of each in percentage of the total area of the sample unit (Figure 4); (b) the deduct values associated with each distress type–severity combination (Figure 5); and (c) the deduct points of each in percentage of the total deduct points (Figure 6). This helps the maintenance decision maker to know the relative effect of each distress type–severity combination on the condition of the pavement as reflected by the number of deduct points.

Finally, the sample unit PCI, computed as described by Shahin and Kohn (*14*), is displayed in Figure 7.

Distress Types ----------- Press any key ...	Density [Percent]		
	Low Sev.	Med. Sev.	High Sev.
1- Alligator Cracking	0.00	6.00	0.00
2- Bleeding	0.00	0.00	0.00
3- Block Cracking	0.00	0.00	0.00
4- Bumps and Sags	0.00	0.00	0.00
5- Corrugation	0.00	0.00	0.00
6- Depression	0.00	0.00	0.00
7- Edge Cracking	0.00	0.00	0.00
8- Jt Reflection Cracking	1.53	0.00	0.00
9- Lane / Shldr Drop Off	0.00	0.61	0.00
10- Long & Trans Cracking	0.00	0.00	0.00
11- Patching & Utility Cut P	0.00	0.00	0.00
12- Polished Aggregate	Has One Severity Level and 0.00 Density		
13- Potholes	0.00	0.00	0.00
14- Railroad Crossing	0.00	0.00	0.00
15- Rutting	0.00	0.00	0.00
16- Shoving	0.00	0.00	0.00
17- Slippage Cracking	0.00	0.00	0.00
18- Swell	0.00	0.00	0.00
19- Weathering and Raveling	0.00	0.00	0.00

FIGURE 4 Density of existing distresses.

Distress Types	Density [Percent] Low Sev.	Med. Sev.	High Sev.
1- Alligator Cracking	0.00	60.00	0.00
2- Bleeding	0.00	0.00	0.00
3- Block Cracking	0.00	0.00	0.00
4- Bumps and Sags	0.00	0.00	0.00
5- Corrugation	0.00	0.00	0.00
6- Depression	0.00	0.00	0.00
7- Edge Cracking	0.00	0.00	0.00
8- Jt Reflection Cracking	3.00	0.00	0.00
9- Lane / Shldr Drop Off	0.00	4.00	0.00
10- Long & Trans Cracking	0.00	0.00	0.00
11- Patching & Utility Cut P	0.00	0.00	0.00
12- Polished Aggregate	Has One Severity Level and 0 D. Points		
13- Potholes	0.00	0.00	0.00
14- Railroad Crossing	0.00	0.00	0.00
15- Rutting	0.00	0.00	0.00
16- Shoving	0.00	0.00	0.00
17- Slippage Cracking	0.00	0.00	0.00
18- Swell	0.00	0.00	0.00
19- Weathering and Raveling	0.00	0.00	0.00

Press any key ...

FIGURE 5 Deduct points due to existing distresses.

Distress Types	Density [Percent] Low Sev.	Med. Sev.	High Sev.
1- Alligator Cracking	0.00	85.11	0.00
2- Bleeding	0.00	0.00	0.00
3- Block Cracking	0.00	0.00	0.00
4- Bumps and Sags	0.00	0.00	0.00
5- Corrugation	0.00	0.00	0.00
6- Depression	0.00	0.00	0.00
7- Edge Cracking	0.00	0.00	0.00
8- Jt Reflection Cracking	6.38	0.00	0.00
9- Lane / Shldr Drop Off	0.00	8.51	0.00
10- Long & Trans Cracking	0.00	0.00	0.00
11- Patching & Utility Cut P	0.00	0.00	0.00
12- Polished Aggregate	Has One Severity Level and 0.00 % of TDP		
13- Potholes	0.00	0.00	0.00
14- Railroad Crossing	0.00	0.00	0.00
15- Rutting	0.00	0.00	0.00
16- Shoving	0.00	0.00	0.00
17- Slippage Cracking	0.00	0.00	0.00
18- Swell	0.00	0.00	0.00
19- Weathering and Raveling	0.00	0.00	0.00

Press any key ...

FIGURE 6 Deduct points (DP) as percentage of total DP.

Sample Unit PCI = 53

... Press Any Key ...

FIGURE 7 Sample unit PCI.

Options

The first three options shown in Figure 8 are provided to facilitate proceeding in the process of data input or help the user move around in the environment of stored data.

Option 4 shows the distress type–severity combinations of the current section extrapolated from distress data of the sample units in that section.

OPTIONS MENU

1- Another sample unit within the same section

2- Another section

3- Another link

4- Density matrix of current section

5- Samples summary output of current section

6- Sections PCI summary output of current link

7- Graphical PCI summary output of current link

8- Combined effect of user selected distresses

9- Consult the on-line EXPERT for maintenance/ Rehabilitation advice for current section

0- End of run

Your Selection [ ]

FIGURE 8 Options menu.

Option 5 (Figure 9) shows a summary output of the current section displaying its sample units, their areas, and their PCI values, and finally the PCI of the entire section and its condition rating.

Option 6 (Figure 10) summarizes the output of the current link, displaying its sections, their areas, their PCI values, and the pavement condition rating.

Option 7 (Figure 11) displays a graphical summary of the branch's condition. This is of particular importance to the decision maker in adjusting the decision of the expert system. For example, suppose a link consists of 25 sections, 24 of which are badly deteriorated, and the expert system's advice is to overlay them all. Only one of the sections is in good condition and requires only some recurrent maintenance such as crack sealing and small patches. In this case, it is more appropriate to take an overlay decision for the entire link, including the one in good condition.

Option 8 enables the user to determine the combined effect of some selected distress types on the condition of the pavement (Figures 12 and 13). To explain, consider the following case: low-severity block cracking extended over a wide portion of the pavement can result in, say, 20 deduct points, yielding a PCI of 80. A localized high-severity alligator cracking can cause the same 20 deduct points, reflecting (but deceptively) the same pavement condition. In fact, alligator

Section : test24

Sample	Area	PCI
10	1182.478	18
30	1074.98	53

Section PCI 67

Section Condition Rating .... GOOD

Press any key

FIGURE 9 Summary of sample units in current section.

Sample	Area	PCI	Rating
test1	50000	72	VERY GOOD
test2	50000	30	POOR
test3	50000	58	GOOD
test4	50000	100	EXCELLENT
test5	50000	100	EXCELLENT
test6	50000	48	FAIR
test7	50000	67	GOOD
test8	50000	32	POOR
test9	50000	74	VERY GOOD
test10	50000	24	VERY POOR
test11	50000	25	VERY POOR

. . . . Press any key . . . .

FIGURE 10 Summary of sections in current link.

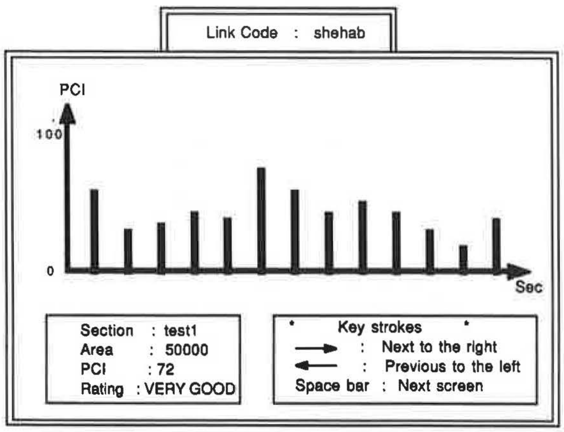

FIGURE 11 Graphical summary of current link.

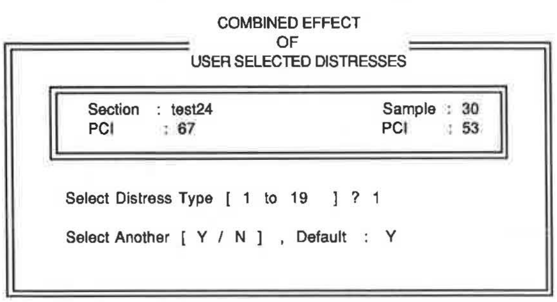

FIGURE 12 Inclusion of distress for combined effect.

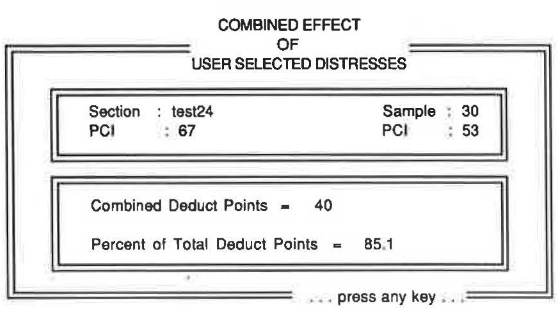

FIGURE 13 Combined effect of chosen distresses.

cracking is one of what are called load-related distresses, the existence of which indicates that the pavement is structurally weak and incapable of carrying the traffic loads. This structural inadequacy might require rebuilding the defected area or at least a full-depth patch. On the other hand, the remedy for the block cracking, which probably developed as a result of pavement aging or shrinkage of the asphalt surface, can be simple crack sealing. This means that although the deduct value is the same in both cases, the causes and remedial actions might differ drastically. So, through this option, the decision maker can choose, for instance, the load-related distresses and examine their combined effect on pavement condition.

Finally, Option 9 prepares for calling the expert system. This option is described in detail in the following paragraph.

First, the program displays all the maintenance activities for the user to determine whether any is not applicable. A maintenance activity may be not applicable for many reasons, such as the lack of materials, the absence of skilled labor or equipment or prohibitive cost. The user can set one activity or more as not applicable or, if difficulties exist but they are not prohibitive, the user can set the activity as applicable but not desirable. This type of data is entered by filling the activity applicability matrix as shown in Figure 14.

Next, the program displays the cost/life matrix (Figure 15), which contains all maintenance activities, each with its unit cost and associated service life. The unit cost can be in the form of the present worth.

At this point, all data are ready for calling the expert system, the output of which will be the M&R activities needed to upgrade the pavement condition.

Expert Consultation

Main Output

The expert system works on the data passed to it by the algorithmic program, using the rules in the knowledge base.

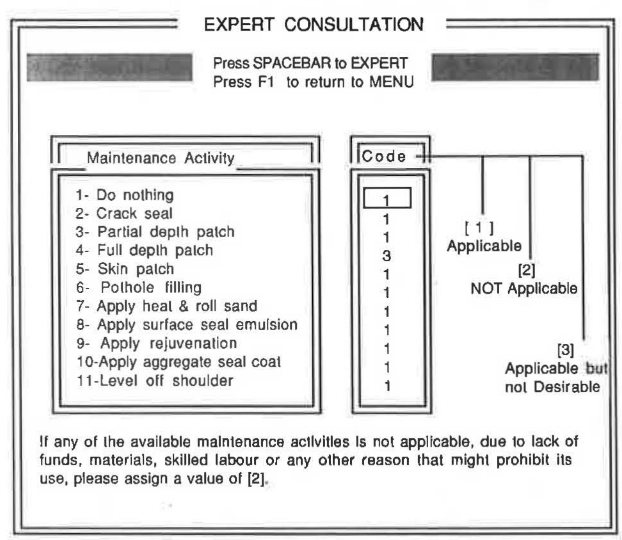

FIGURE 14 Activity applicability matrix.

EXPERT CONSULTATION

Press SPACEBAR to EXPERT
Press F1 to return to MENU

Maint. Activ.	unit	cost	Life	Maint. Activ.	unit	cost	Life
Crack seal 1	sq m	2.00	1.00	Skin patch	ln m	1.70	1.00
Crack seal 1	ln m	1.00	1.00	Pothole fill	pothol	0.50	1.00
Crack seal 2	ln m	0.05	1.00	Roll sand	sq m	0.35	1.00
P depth patch	sq m	8.00	1.00	S S emulsion	sq m	2.50	1.00
P depth patch	ln m	4.00	1.00	S S emulsion	ln m	1.25	1.00
P depth patch	pothol	3.00	1.00	Rejuvention	sq m	2.50	1.00
F depth patch	sq m	12.50	1.00	Rejuvention	ln m	1.25	1.00
F depth patch	ln m	6.25	1.00	Agg seal coat	sq m	3.00	1.00
F depth patch	pothol	4.2	1.00	Agg seal coat	ln m	1.50	1.00
Skin patch	sq m	3.5	1.00	level & seal shoulder	ln m	2.00	1.00

FIGURE 15 Cost/life matrix.

Using the PCI value of the current section and PCI limits that correspond to the highway class, the expert system determines whether to rehabilitate the entire pavement section or to make localized remedial actions for each existing distress type.

Examples of the rehabilitation decision are (a) apply a thin (functional) overlay, (b) apply a thick (structural) overlay, or (c) strengthen the pavement and then apply an overlay. The type of rehabilitation depends on the PCI value and the class of the highway. An example of the output screen is shown in Figure 16: the pavement section needs a thin overlay, and because this solution is unique (i.e., there are no possible alternatives), it takes a probability value of 10 (the maximum on a 0–10 scale).

If the pavement condition does not dictate rehabilitation, the expert system determines the suitable maintenance actions, gives them equal probability of 5, then checks whether any of the candidate actions is not applicable. If so, it is assigned a lower probability value of 1. The rest of the applicable activities are mutually compared for cost effectiveness, and the one that has lower cost/life value is assigned a higher probability value of 9.

Finally, a list of all candidate activities is displayed, the activities arranged according to final averaged probability value—the most likely first, the next likely second, and so on. For example, for a medium-severity depression, and according to activities applicability and cost/life data shown in Figure 17, the output takes the form shown in Figure 18, which indicates that a partial-depth patch is the most probable maintenance action to be taken. Besides, a comparison of the probability values indicates the relative likelihood of maintenance actions. If more than one maintenance action receive equal final probability values, they are displayed in alphabetical order, which means no real difference in rank. The process repeats until all existing distress types are considered.

Supporting Outputs

The normal options available in most expert system shells were used in this program to provide the user with several supporting outputs as described in the following.

	Values based on 0 - 10 system	VALUE
1	Thin overlay	10

All choices <A>, only if value > 1 <G>, Print <P>, Change and rerun <C>, rules used <line number>, Quit/save <Q>, Help <H>, Done <D>:

FIGURE 16 Example of rehabilitation output.

1 - Distress type is Depression
2 - Severity level is Medium
3 - Do nothing is Not applicable
4 - Crack seal is Applicable
5 - Partial depth patch is Applicable
6 - Full Depth patch is Applicable but not desirable
7 - Skin patch is Applicable
8 - Pothole filling is Applicable
9 - Apply heat & Roll sand is Applicable
10-Apply surface seal emulsion is Applicable
11- Apply rejuvenation is Applicable
12- Apply aggregate seal coat is Applicable
13- Level off shoulder and apply aggregate seal coat is Applicable
14- Variable [PCI] = 82.000000
15- Variable [COST PDP] = 8.000000
16- Variable [LIFE PDP] = 1.000000
17- Variable [COST FDP] = 12.500000
18- Variable [LIFE FDP] = 1.000000
19- Variable [COST SP] = 3.500000
20- Variable [LIFE SP] = 1.000000

Enter number of line to change, <0> for original data, <R> to run the data, <H> for help or any other key to redisplay data :

FIGURE 17 Data summary.

	Values based on 0 - 10 system	VALUE
1	Partial depth patch	7
2	Skin patch	7
3	Full depth patch	5

All choices <A>, only if value > 1 <G>, Print <P>, Change and rerun <C>, rules used <line number>, Quit/save <Q>, Help <H>, Done <D>: 1

FIGURE 18 Example of maintenance output.

Tracing the Decision The system allows the user to trace back how the program arrived at its final value for a specific choice by entering the line number of any choice; the program will respond by displaying all rules used to determine the value of that choice. For instance, in Figure 18, a user who wants to know how the final value for the partial-depth patch was reached would enter "1," which is the line number for this choice, and the computer displays the rules as shown in Figure 19.

RULE NUMBER :18

IF :

(1) Action is Maintenance
and (2) Distress type is Depression
and (3) Severity level is Medium or High

THEN

Possible maintenance action is partial depth patch
and Possible maintenance action is full depth patch
and Possible maintenance action is skin patch
and Full depth patch - Probability = 05/10
and Skin patch - Probability = 05/10

RULE NUMBER : 51

IF :

(1) Action is Maintenance
and (2) Possible maintenance action is partial depth patch
and (3) Partial depth patch

THEN :

Partial depth patch - Probability = 07/10

RULE NUMBER : 73

IF :

(1) Partial depth patch >= 05/10
and (2) Full depth patch >= 05/10
and (3) [COST PDP] / [LIFE PDP]<[COST FDP]/[LIFE FDP]

THEN :

Partial depth patch - Probability = 09/10

FIGURE 19 Asking how conclusions were drawn.

Checking Triggered Rules When a rule is displayed, the user has the option of asking how the computer knows a condition in the IF part is true. To do this, the user enters the line number of the IF condition. The computer will answer with one of several responses:

1. It may display the rule or rules that led it to derive the information. A rule used for derivation will have information about the condition the user is asking about in its THEN part. The user can then continue asking how the computer knew that the rule's IF conditions were true and so on until the end of the chain of rules.
2. The computer may respond that the user provided the information to the program.
3. If the information was provided by an external program call, the computer gives the user the name of that program.
4. The computer may respond that it does not yet know if the condition is true or not. This can occur when the user asks the computer WHY in response to its question. The rule displayed may not have been fully tested yet.

Changing and Rerunning Of the very powerful facilities given to the user is the change and rerun option. It is an easy way to test how changes in input affect conclusions. The user can change one or more items of the input data while holding the others constant, rerun the program using the adjusted data, and see the effect of the changes on the outcome. The original values of the choices can be saved for comparison with the new values.

This option gives the maintenance decision maker the ability to have a dialogue with the expert system. Considering the previous example of medium-severity depression, suppose that the decision maker wants to see what happens if partial-depth patches are not applicable. Changing Item 5 in Figure 17 to "partial-depth patch is not applicable" will yield the new output shown in Figure 20, along with the previous output for comparison.

To change the data, the user is asked if he or she wishes to save the current values for comparison with the new ones that will be calculated. The program will then display a list of all information that the user provided earlier. The user enters the number of the statement to be changed and the

	Values based on 0 - 10 system	VALUE	PREV.
1	Skin patch	7	7
2	Full depth patch	5	5
3	Partial depth patch	3	7

All choices <A>, only if value > 1 <G>, Print <P>, Change and rerun <C>, rules used <line number>, Quit/save <Q>, Help <H>, Done <D>:

FIGURE 20 Changing and rerunning data.

program will ask for changes. The user answers the questions with the new data to be tried and continues changing statements. If, because of the changes the user made, the program needs more information, it will ask for it. The program finally displays the new list of choices. If the user opted to have the previous values saved for comparison, they too will be displayed.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

In this research effort, a microcomputer-based pavement maintenance decision support system was developed using artificial intelligence and expert systems technology. This system is intended to be a stand-alone or independent maintenance decisions support system and to be part of a continuing effort to produce an integrated pavement maintenance management system. The developed system is twofold so that it allows for pavement condition monitoring and evaluation via an algorithmic program using the PCI procedure. It also allows the user to select the most appropriate maintenance or rehabilitation actions needed to upgrade the condition of the pavement via an expert system program.

The developed system is easy to use, and, more important, the knowledge base of the expert system is adaptable to incorporate new maintenance and rehabilitation strategies and to expand the user-expert consultation details when required.

Conclusions

The outcome of this work is not a new theory, a new understanding of an existing one, or any other theoretical output. Instead, it is a practical output in the form of a simple working system built to fulfill the need of the Egyptian highway agencies and engineers involved in pavement evaluation and maintenance. The developed system represents an attempt to apply the technology of artificial intelligence and expert systems to the domain of pavement maintenance management in developing countries. However, added to the value of the developed pavement maintenance management expert system, a number of conclusions can be drawn:

1. A pavement maintenance management expert system is possible, justified, and appropriate, and pavement management is an ideal application area for expert systems technology.
2. The large number of mathematical computations involved in a pavement maintenance management system makes the development of an expert system difficult. To overcome this problem, an algorithmic program using one of the conventional programming languages can be built to relieve the burden of these computations and free the expert system program to handle the heuristic rules supporting the maintenance decisions.
3. This expert system will be valuable to Egyptian highway agencies, especially the local limited ones, that lack in-house expertise. It is also a useful tool for novices to enhance their M&R skills.

Recommendations

To enhance the system capabilities, the following recommendations are suggested:

1. Pavement evaluation not only should be based on visual inspection data but also must incorporate roughness, a measure of structural capability, and a safety measure. This will enhance the exactness and effectiveness of M&R decisions.
2. A life-cycle cost-analysis procedure, including modules to calculate the service lives of M&R alternatives, can replace the user in providing the necessary data for the cost/life matrix.
3. An external data base including information on material, labor, and equipment requirements for different M&R alternatives can ease (or replace) the task of filling the activity applicability matrix.
4. Other rehabilitation techniques not now included can be added if applicable.
5. The system assumes that the M&R activities will be performed at the same year of evaluation, which is almost never the case. The system can be enhanced to allow the user to specify the year of implementation and have the system give M&R advice appropriate for the pavement's projected condition in that year.

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