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A DECISION SUPPORT EXPERT SYSTEM FOR MAINTENANCE AND REHABILITATION NEEDS

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Abstract

This paper presents a description of an expert system developed to assist local highway agencies in developing countries in managing pavement maintenance. A two module system has been developed for this purpose. The first module is in the form of an interactive algorithmic program that simulates the evaluation phase and creates a complete diagnostic report of the pavement condition using the Pavement Condition Index (PCI) procedure.

INTRODUCTION

Most of the in-service pavements were built years ago, few new pavements are being constructed now. Increasing traffic volumes and weights in conjunction with the lack of periodical maintenance have caused the pavement to deteriorate to conditions considered "a functional failure". They do not perform their intended functions of serving the users safely and comfortably, rather they damage vehicles, slow travel, increase fuel consumption, and in some cases are hazardous to ride on.

Pavement networks need both localized maintenance (eg crack sealing, pothole filling ... etc) and extended rehabilitation of entire pavement sections in order to keep the pavement in a serviceable state.

In developing countries, such as Egypt, highway agencies do not have an efficient system for managing the investments in pavement maintenance and rehabilitation (M&R). The selection and scheduling of the appropriate M&R activities to a diversity of roadway section types, conditions, traffic characteristics ... etc have proved to be a formidable task. Many components of M&R decision making are complex and poorly structured. The decision of M&R requires high cognitive skills and multi objective decision making which require the knowledge and collective judgement of highly qualified pavement experts.

Artificial Intelligence (AI) applications in the area of transportation engineering, in general, and in pavement management systems (PMS), in particular, are receiving considerable attention from transportation and highway agencies. AI is a field concerned with designing and programming machines to accomplish some of the tasks that people accomplish using their intelligence (Rich, 1983). It is a branch of computer science which aims to make computers act intelligently whilst solving complex problems (Brown, 1984).

Expert systems, a subset of AI, are programs which aim to emulate and imply human knowledge and expertise in a particular domain. Expert systems have great potential for solving problems that require expertise and collective judgement of human experts.

Thus, expert systems constitutes a promising technology as a M&R decision support tool because of their ability to systematically formalize and use the thought process and experience of experts. This is particularly true for developing countries, where expert systems can play an important role in offsetting the lack of experience.

RESEARCH OBJECTIVE

This research aims, specifically, at developing an integrated practical personal computer-based decision support expert system for highway pavements M&R needs to assist local highway agencies that lack in-house pavement experts.

Hopefully, the system will provide full decision support for novice pavement engineers. It is expected that the system implementation will upgrade their performance to reach experts-level decisions. It is also expected that the complete system, once implemented, will save the agencies time and prevent M&R project delay due to absence of the necessary experts.

RESEARCH APPROACH

As mentioned earlier, the problem of M&R decision making constitutes a set of complicated and interrelated activities which requires heuristic knowledge and collective judgement and expertise of highly qualified pavement experts. This makes purely algorithmic programming difficult if not impossible. Conversely, both pavement evaluation, the diagnosing phase of the decision making process, and cost estimation process require excessive complex computations as well which can be better handled using algorithmic programming.

The system is, therefore, developed as a combination of algorithmic and heuristic programming technologies. This helps in capturing the advantages of both programming technologies leading to a more integrated structure. The algorithmic components carry the burden of the excessive amount of computations whilst the heuristic component is better suited to the heuristic nature of human expertise.

SYSTEM DEVELOPMENT

The system development can be viewed as five highly interdependent phases, namely: identification, conceptualization, knowledge acquisition, encoding, and testing. Figure 1 illustrates these phases interaction while a brief description of each phase is presented below.

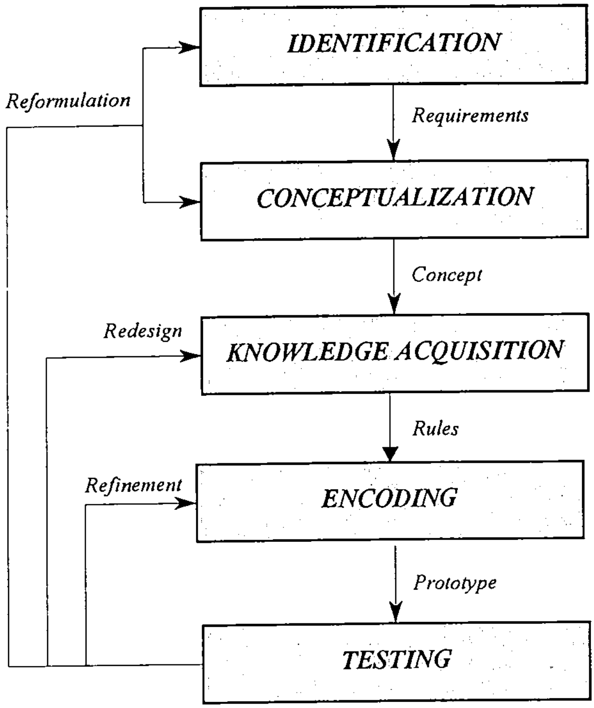


Figure 1 System development phases

Identification

The first phase of the system development was to identify the objective and general concept of the developed system. This phase also included a literature review to obtain a general overview of the M&R problem and its characteristics. In addition this phase is concerned with identifying and selecting the participating experts and resources including the available computing facilities.

Conceptualization

In this stage the development tool was decided and the general structure of the system was determined. The Algorithmic module of the developed system was developed using Microsoft QuickBASIC. QuickBASIC combines a total programming environment with a very powerful BASIC language. It constitutes very powerful programming features together with a full graphics support. Like most other powerful programming tools, QuickBASIC provides the programmer to mix the editing, running, and debugging the program in any way he wants, because all the programming tools are up and running all the time.

On the other side, the heuristic module (expert system) was developed using the EXSYS rule-based shell. Rule based systems, by far, are the most popular knowledge representation techniques for diagnostic style systems (Buchanan, 1984). Rules are particularly appropriate when domain knowledge results from empirical associations developed through years of problem solving expertise (Waterman, 1986).

EXSYS is one of the most commercial available rule-based shells. EXSYS is somewhat inflexible, but nevertheless locally well known and widely used. It forms a suitable environment as it is easy to learn and facilitates speedy development and delivery of operational systems. One of its features is its ability to interface with external programs. This feature is used to firstly run the algorithmic subsystem for the intensive computations and customize the user interface.

Knowledge acquisition and formalization

This stage involved the knowledge acquisition and formalization sessions. Knowledge acquisition is the "transfer and transformation of problem solving expertise" (Hayes Roth, 1983). It is the process by which the experience encapsulated within the mind of the expert is acquired (Miles and Moore, 1991). Knowledge acquisition has alternately been referred to as "knowledge extraction" or "knowledge elicitation". However, knowledge acquisition is currently referred to as one of the most important aspects of expert system development. Moore and Miles (1991) mentioned knowledge acquisition as the most problematic area of building an expert system.

In this project, a detailed knowledge acquisition methodology has been carried out. Two in-parallel knowledge acquisition approaches has been followed with two domain experts individually, the interviewing approach and the observation approach. A large amount of knowledge has been acquired on the domain of pavement M&R. The knowledge acquisition session showed that the decision making process relies on both deterministic knowledge and heuristic knowledge. Deterministic knowledge concerns the diagnostic nature of the pavement evaluation process. On the other side, heuristic knowledge concerns the decision logic which is based on collective judgement and expertise of highly qualified experts. This knowledge acquisition methodology proved to be productive and has successfully acquired a large number of both knowledge types. The problems encountered in the knowledge acquisition session of this project were common. However, it is not the aim of this paper to discuss the knowledge acquisition effort.

Knowledge formalization is the formalization of the acquired knowledge in the rule-format of the selected development tool.

Encoding

This stage presents encoding the acquired knowledge in the system knowledge base. The prototype development and rule formulation and coding was assisted by the EXSYS editor. Modifications and refinements were then carried out to correct and/or enhance the system knowledge base. Although the selected development tool revealed some difficulties because of its rigid rules format, its rule editor and supporting options helped in the encoding process especially in highlighting the knowledge base conflicts (EXSYS, 1985).

Testing

This stage presents the system evaluation. The system conclusion and reasoning was first measured compared with human experts. Revisions and refinements were then performed using additional advice from the experts. The system is currently subjected to a detailed undergoing evaluation to assess its overall competence and suitability for industrial use.

SYSTEM ARCHITECTURE

The system structure has been subjected to several modifications and refinements during the system development. However, the basic architecture of the developed system is presented in Figure 2 while a summarized description is presented below. In addition, a detailed description of the system performance is presented in the following section.

The evaluation subsystem

This is the primary component of the developed system. It presents a structured algorithmic program for pavement condition evaluation to support the diagnostic phase of the decision making process. This subsystem handles the Pavement Condition Index (PCI) calculation, distress cause determination, combined distresses effect, and overall evaluation results. It finally generates a report on the pavement condition which presents the context or the data base of the expert subsystem.

The expert subsystem

This subsystem presents the heuristic module of the developed system. It is concerned with determining and ranking the M&R needs. It manipulates the distress data and pavement condition report generated by the evaluation subsystem to assess the appropriateness of different M&R alternatives. This subsystem is developed in a standard rule based expert system. It constitutes the basic architecture of expert systems (knowledge base, inference engine, explanation facility, user interface, and context). Its inference engine uses a backward chaining mechanism. The system knowledge base presents the knowledge and expertise acquired from two in-house highly qualified pavement experts.

The setup subsystem

This subsystem presents a user modifiability option of the M&R alternatives. It enables the user to assign, alter, or eliminate the applicability of different M&R alternatives. It also enables the user to alter the initial unit cost and/or service life of these alternatives. This component can be executed as a stand alone program prior the system application to enable each agency to adapt the system according to its local requirements. The user, also, has the option to access this subsystem through the global system.

The cost estimation subsystem

This subsystem presents an algorithmic program to calculate the cost of the M&R needs recommended by the expert subsystem. It enables the user to compare between the cost/life of the different appropriate alternatives. It also determines the total required budget for the pavement under consideration. This subsystem is executed directly by the expert subsystem to cover the costing aspects based on the locally assigned unit costs and service lives.

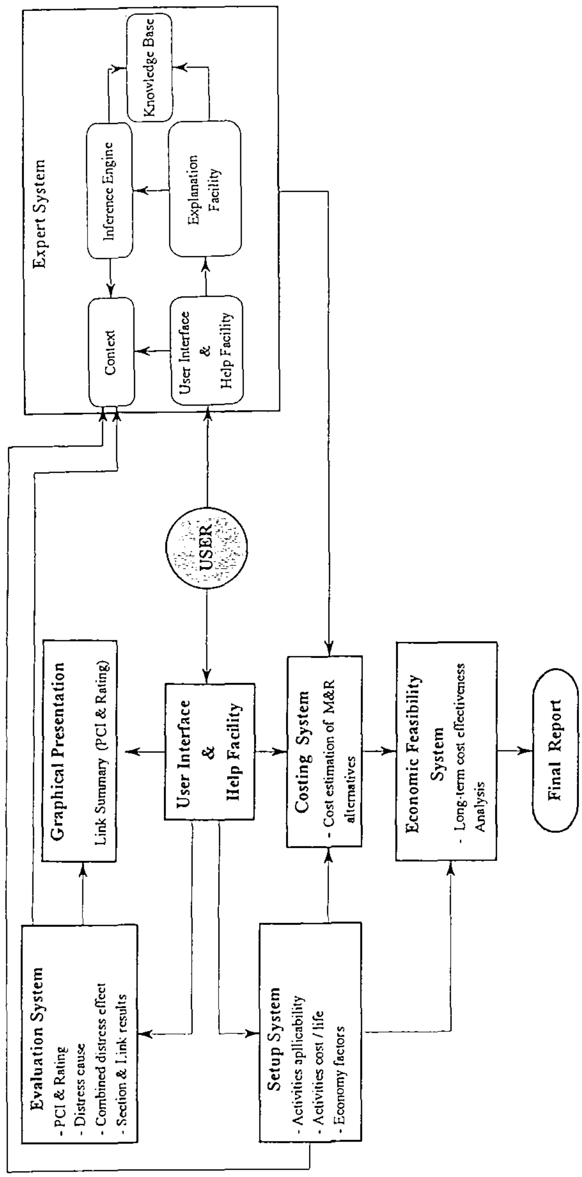


Figure 2 System architecture

The economic analysis subsystem

This subsystem is an optional component. It performs an economic feasibility analysis to enable the user to perform a long term comparison between different M&R strategies using the present worth economic analysis methodology (White et al. 1989). This subsystem incorporates a long term prediction model for pavement future performance and the associated operating and routine maintenance cost.

The graphics subsystem

This component enables the user to access and scroll different graphical presentations of the output results.

The user interface

The user interacts with the different system components through a friendly user interface. The end user was largely incorporated in the design of the system user's interface. User needs and inquiries provided the bases of the system structure and contents. The developed user interface is a combination of menu-driven and pictorial icons formats. Two separate user interfaces are developed. The first coordinates the different algorithmic system components and includes a simplified data manager that controls data input, arrangement, storage and retrieval. The second concerns the expert system component. A "Help" facility is also included and can be executed upon user request.

Explanation facility

The expert subsystem provides the user with the option to explain its conclusion and reasoning by tracing its problem solving process. In addition an explanation window is also incorporated for each input question.

SYSTEM DESCRIPTION

A step by step demonstration of the system performance is presented below.

The evaluation subsystem

Input

When considering new data, the program responds querying informative on the identification data which includes link code, section code and its area, sample unit number and its area. The next input required is the distress data. Figure 3 shows the distress input screen which includes the distress types considered and the units in which they are used. The user supplies the data from the condition survey sheet at random and the system will rearrange and accumulate it. The system provides the user with the option to change any of the input data upon his request.

Output

The program arranges the output as follows:

- *The density matrix:* It includes the density of each distress type/severity ie. the amount of each as a percentage of the total sample unit area.
- *The deduct values:* Presents the individual deduct points associated with each distress type/severity according to the PCI approach. Figure 4 presents an example of the deduct values of a certain sample unit.
- *The deducts percentage:* Presents the percentage of the individual deduct points of each distress type/severity of the total deduct points. This is beneficial as the user can read the

relative effect of each distress type/severity on the condition of the pavement as reflected by the amount of deduct percentage.

- *Sample unit's PCI:* Finally, the sample unit PCI, computed using the Pavement Condition Index approach, is displayed.

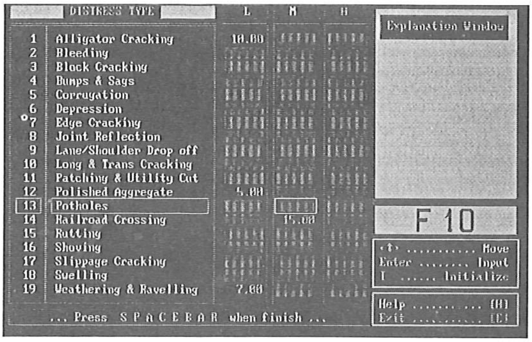


Figure 3 Distress input screen

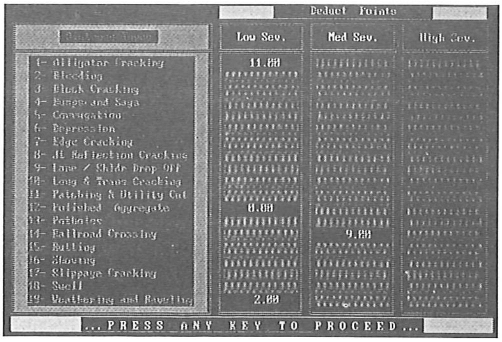


Figure 4 Example existing distress types/severity deduct points (PCI˙ approach)

The expert subsystem

The user can access the expert system from the main menu. When calling the expert subsystem, the program inquires about the highway characteristics (Traffic volume, travelling speed ...etc.). The program then inquires about the pavement condition history (Figure 5). This includes the previous pavement conditions in terms of the previous evaluation's PCI, the rate of previous maintenance in terms of the patched area ratio, any previous strengthening and the age since this strengthening or since construction.

Finally, the system inquires about the pavement skid resistance. If not possible or not measured, the system automatically analyzes the distress data to estimate the skid resistance level.

At this point, the diagnostic phase has been completed and a detailed report on pavement condition is performed. This report includes the information required for calling the expert subsystem to determine the suitable M&R activities needed to upgrade the pavement condition. This information includes the following:

- Traffic volume
- Section's PCI

- Short and long term rates of deterioration
- Level of previous maintenance
- Skid resistance
- Applicable M&R activities based on the local circumstances
- Unit cost and projected service life of each activity
- Existing distress types/severity.

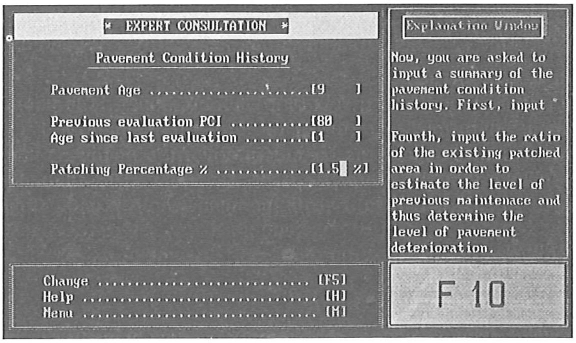


Figure 5 **Expert consultation (pavement condition history)**

The expert system receives the pavement condition data acquired by the diagnostic phase. The system uses this data to differentiate between four major M&R paths, namely, do nothing, recurrent Maintenance, periodic maintenance (rehabilitation), and strengthening (reconstruction).

The *Do nothing* path means that the pavement is in a good condition and does not need any activity except continuing the routine maintenance.

The *Maintenance* path includes 10 different localized remedial activities. The expert subsystem manipulates the existing distress types/severity individually to determine their corresponding appropriate maintenance activities. It then checks their applicability according to the agency's local capabilities. A list of all appropriate activities for the considered distress type is then displayed. The rehabilitation path includes two major activities, namely, applying thin (functional) overlay, and applying thick (structural) overlay. The strengthening path means that the section had badly deteriorated and incapable of carrying the existing traffic loads. This reveals the need for increasing its load carrying capacity (strengthening and overlay).

The setup subsystem

This system component presents the system's user/agency modifiability option. It provides the user with the option to setup the M&R activities applicability, M&R activities cost/service life, and/or the economic analysis factors as described here.

Activities applicability setup

The M&R activities included are general. Therefore, some of these activities may be not applicable to small local agencies for reasons such as lack of materials, equipment and/or skilled labor. Figure 6 shows the activities applicability setup screen. The user can set an activity as inapplicable or as not recommended if such activity would be problematic.

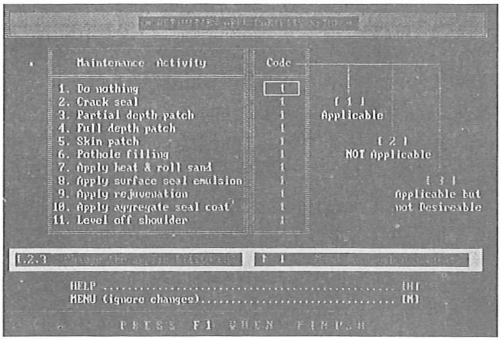


Figure 6 **Activities applicability setup**

Activities cost/life setup

The included M&R activities cost/service are very much agency/region dependent because of the wide variation in material types and labor costs. The included cost/service life presents the data collected from a local survey. This setup option enables the user to change the cost and/or projected service life of any activity according to his local circumstances.

Economic factors setup

This option enables the different agencies to set the interest rate, inflation rate, and/or rate of increase in funds according to their local/national circumstances.

Cost estimation subsystem

The cost estimation subsystem calculates the total cost of the assigned M&R alternative. If the expert system concluded that the current section requires a set of localized maintenance activities, the cost estimation subsystem displays a cost analysis screen (Figure 7). When the user select any of the appropriate activities for each distress type. The system responds by calculating and printing this activity cost/year of service life in the right part of the screen. The user can then move to another distress type using the key strokes or change the selected activity. The system responds by calculating the individual cost of this activity and updating the total cost. Finally, the system displays the decision and its associated cost.

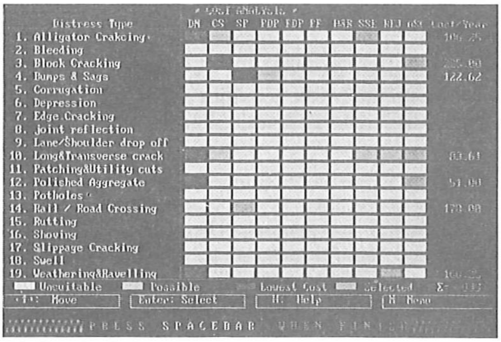
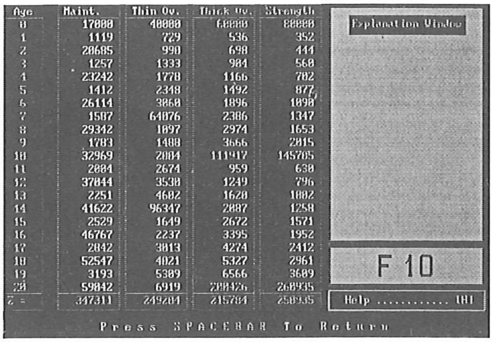


Figure 7 **Cost analysis screen (maintenance strategy)**

Economic analysis subsystem

This subsystem enables the user to predict and compare the cost effectiveness of the different M&R alternatives through an economic analysis using the Equivalent Uniform Annual Cost approach (White, 1989). Figure 8 shows an example of the economic analysis results.



Age	Maint.	Thin Ov.	Thick Ov.	Strength
0	17000	40000	60000	80000
1	1119	729	536	352
2	20685	990	698	444
3	1257	1333	984	560
4	23242	1778	1166	702
5	1412	2348	1492	877
6	26114	3060	1896	1090
7	1587	64076	2386	1347
8	29342	1097	2974	1653
9	1783	1488	3666	2015
10	32969	2004	111917	145705
11	2004	2674	959	630
12	37044	3530	1249	796
13	2251	4602	1620	1002
14	41622	96347	2087	1258
15	2529	1649	2672	1571
16	46767	2237	3395	1952
17	2842	3013	4274	2412
18	52547	4021	5327	2961
19	3193	5309	6566	3609
20	59042	6919	280426	260935
Σ =	347311	249204	215784	250935

Figure 8 **Example predicted cash flow of M&R alternatives**

The graphical presentation subsystem

This subsystem provides a bar-chart presentation of the evaluation summary as well as the associated M&R cost. Figure 9 presents an example of the graphical presentation screen. It also provides a presentation of the economic analysis results.

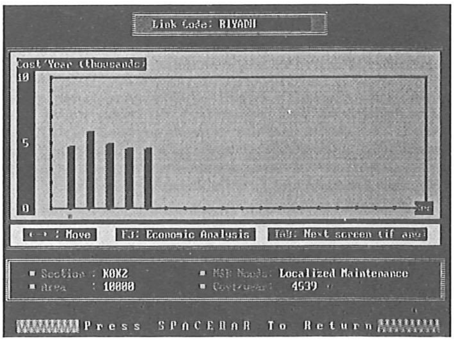


Figure 9 **Example graphical presentation of link M&R costs**

Help and explanation facilities

The system provides the user with a supporting "Help" facility to explain the expert consultation procedure. In addition, the system provides the user with an on-line window to explain the current input inquiry (question).

Results printout

The user has the options of printing the final report on the screen, disk file, and/or printer. This final report includes the evaluation results summary, the M&R decision, and the total associated cost. Figures 10a and 10b present an example of a final report printed on the screen.

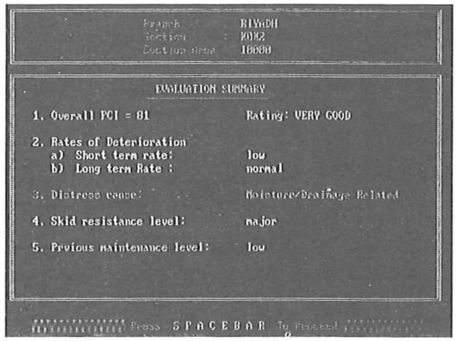


Figure 10a **Example section M&R report (1/2)**

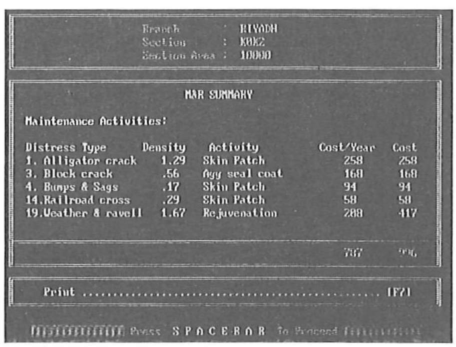


Figure 10b **Example section M&R report (2/2)**

HARDWARE

At an early stage of this project, the decision was taken to develop the system on PCs. The justification of this decision is that the system be portable and suits small local highways computer facilities. Work stations are not as available as PCs in these agencies. In addition, the problem of different operating systems and internal configurations would largely limits the system's applicability (Miles and Moore, 1994).

The system works under MS-DOS IBM PCs and compatibles. It requires a minimum configuration of 386 processor with DOS 5 which is,virtually, available in every local highway agency. However, a higher configuration would reduce the system's execution and running time.

SUMMARY

In this research effort, a microcomputer based Pavement Maintenance and Rehabilitation decision support tool was developed. This system presents an integrated stand-alone or independent M&R decision support tool. The system is developed in a highly interrelated combination of algorithmic and heuristic programming technologies.

The primary component of the system is in the form of an interactive algorithmic program that simulates the diagnostic (evaluation) phase of the decision making process. It allows for pavement condition monitoring and evaluation using the PCI procedure. The system also provides a graphical presentation of the evaluation results summary. The heuristic module of the developed system (expert system) allows for an on-line expert consultation on the M&R altematives needed to upgrade the pavement condition.

The costing component simulates a detailed industrial cost estimation procedure to determine the total required budget. Furthermore, the system incorporates a long term economic analysis of the M&R investments which is extremely important for successful industrial decision support systems.

The system incorporates a friendly user interface and a detailed help and explanation facility. It also incorporates a simplified data manager that carries the burden of data input, storage, and retrieval and allows the link with the data base of the global pavement maintenance management system.

CONCLUSIONS

The outcome of this work effort is not in the form of a new theory, or a new understanding of an existing one, or any other theoretical output. Rather, it is a practical output in the form of an industrial working system that was built to fulfill the need of the local highway agencies and engineers involved in the field of pavement evaluation and maintenance. The developed system presents a simplified, but nevertheless successful application of artificial intelligence and expert systems in conjunction with engineering economic analysis to the domain of pavement maintenance management in developing countries.

However, added to the value of the developed decision support system, a number of conclusions can be drawn:

i) A pavement maintenance management expert system is possible, justified, appropriate, and thus feasible and useful.

ii) The large amount of mathematical computations involved in a pavement maintenance management system makes the development of an expert system difficult. To overcome this problem, an in-parallel algorithmic program can be built to relief the burden of these computations and set the expert system free for handling the heuristic phase of the decision making process.

iii) Practical M&R decisions can not be made without great attention to the corresponding costs and, hence, the required budget. Furthermore, feasible M&R decisions can not be approached without a detailed long term economic feasibility analysis.

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