Development of Project-Level Urban Roadway Management System

XIN CHEN, TERRY DOSSEY, AND W. RONALD HUDSON

The second part of the Urban Roadway Management System (URMS), the project-level pavement design and maintenance subsystems, is described. In the design subsystem the AASHTO flexible pavement design procedure is applied to the process of structural design of new pavements and overlay pavements. A linear programming model for obtaining the least-cost solutions for new flexible pavement design problems is included. As a part of the URMS package the design subsystem can automatically retrieve needed information from the network-level URMS. The design subsystem can also be used as a stand-alone program. The maintenance subsystem is an application of a simplified expert system for selecting cost-effective distress repair methods. The simplified expert system is designed in such a way that each distress type is related to a maximum of three variables and each variable is further divided into a maximum of three levels. At least 27 repair methods for each distress type can be defined. Both the design and the maintenance subsystems are easy to learn and use with the graphical user interface.

The Urban Roadway Management System (URMS) is a comprehensive pavement management system at the network level and project level developed primarily for application in small and medium-sized cities. It is a simple, flexible, and user-friendly computer program with a graphical user interface.

As shown in Figure 1 the complete URMS consists of four subsystems: planning at the network level and design, construction, and maintenance at the project level. The objective of the planning subsystem is to identify and select cost-effective Maintenance and rehabilitation (M&R) projects at the network level. The M&R strategies assigned for the candidate projects selected in the planning subsystem are combined into four types: reconstruction, overlay, routine maintenance, and do nothing. The design subsystem selects materials and determines the layer thicknesses for those projects scheduled for overlay and reconstruction. The management of the work zone for the overlay and reconstruction will be included in the construction subsystem. The maintenance subsystem is used to select cost-effective distress repair methods for projects targeted for routine maintenance by the planning subsystem.

The network-level planning subsystem has been documented elsewhere (*1*). This paper focuses on the project-level design and maintenance subsystem. In the design subsystem the two major models are the AASHTO flexible pavement design procedure and the linear programming model for new pavement design. The AASHTO pavement design procedure has previously been described in detail (*2*), and the linear programming model for AASHTO flexible pavement design has also been documented elsewhere (*3*). This paper concentrates on the computer program developed for the design subsystem. The maintenance subsystem is constructed as a simplified expert system for selecting cost-effective distress repair methods. It is designed in such a way that each distress type is related to a maximum of three variables and each variable can have a maximum of three levels. The system can be used as an expert system tool for any user to build his or her own expert system with little knowledge of expert systems.

X. Chen, Texas Research and Development Foundation, 2602 Dellana Lane, Austin, Tex. 78746. T. Dossey and W. R. Hudson, Center for Transportation Research, ECJ 6.10, The University of Texas at Austin, Austin, Tex. 78712.

DESIGN SUBSYSTEM

The design subsystem consists of four major modules: a data base module, an AASHTO design model module, a linear programming model (LPM) module, and a report module. The data base module stores all of the information related to a flexible pavement design problem. The AASHTO flexible design procedure is used to calculate the structural number of each layer for the overlay and new pavements. The LPM module can find the least-cost solutions for the thicknesses of the three layers to the new flexible pavement design problems. The report module displays and prints the input and output.

Figure 2 shows the data flow diagram for the design subsystem. The design data base retrieves the related information from the planning data base if the design subsystem is used as a part of the URMS; additional data are entered manually. For stand-alone use all of the input data are entered manually.

The program selects the least-cost materials by using the ratio of the layer coefficient multiplied by the drainage coefficient to the unit cost of each material (*3*). The AASHTO model then determines the structural number for the material selected for each layer. For overlay design the surface overlay thickness is determined directly. For new pavement design two procedures are adopted: optimal design and conventional design. The optimal design can determine the optimal thicknesses for each of the three layers (surface, base, and subbase), which minimizes the total construction material cost. The conventional design allows the user to design layer thickness interactively; that is, the user enters one or two of the layer thicknesses and the program calculates the rest. This function provides the user with a useful tool for construction dynamic quality control (*4*) in which the pavement layer thicknesses during construction can be adjusted to meet the design specification.

One of the features of the design subsystem is to import data from the planning subsystem. Those M&R sections selected for overlay (including thin, medium, and thick overlays) will be retrieved from the planning data base and saved to the design data base. The main screen for importing data is shown in Figure 3. All the sections retrieved from the planning data base are drawn in the color-coded map (dotted lines in the map in Figure 3), and the section identification displayed in the left part of the screen is highlighted in the map (not shown in Figure 3). The street names are not shown on the

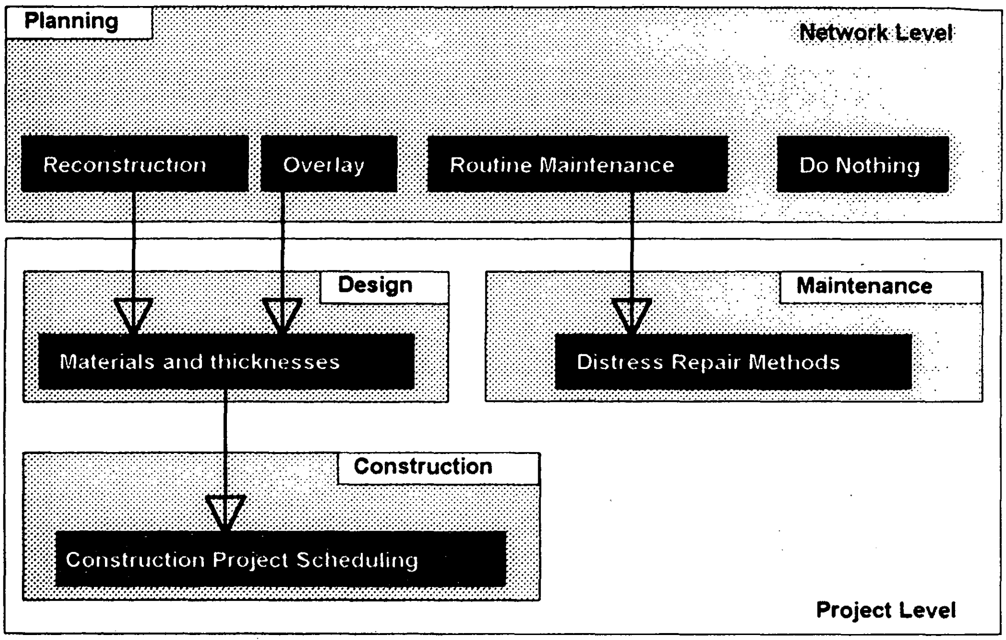


FIGURE 1 Overall structure and data flow diagram of URMS.

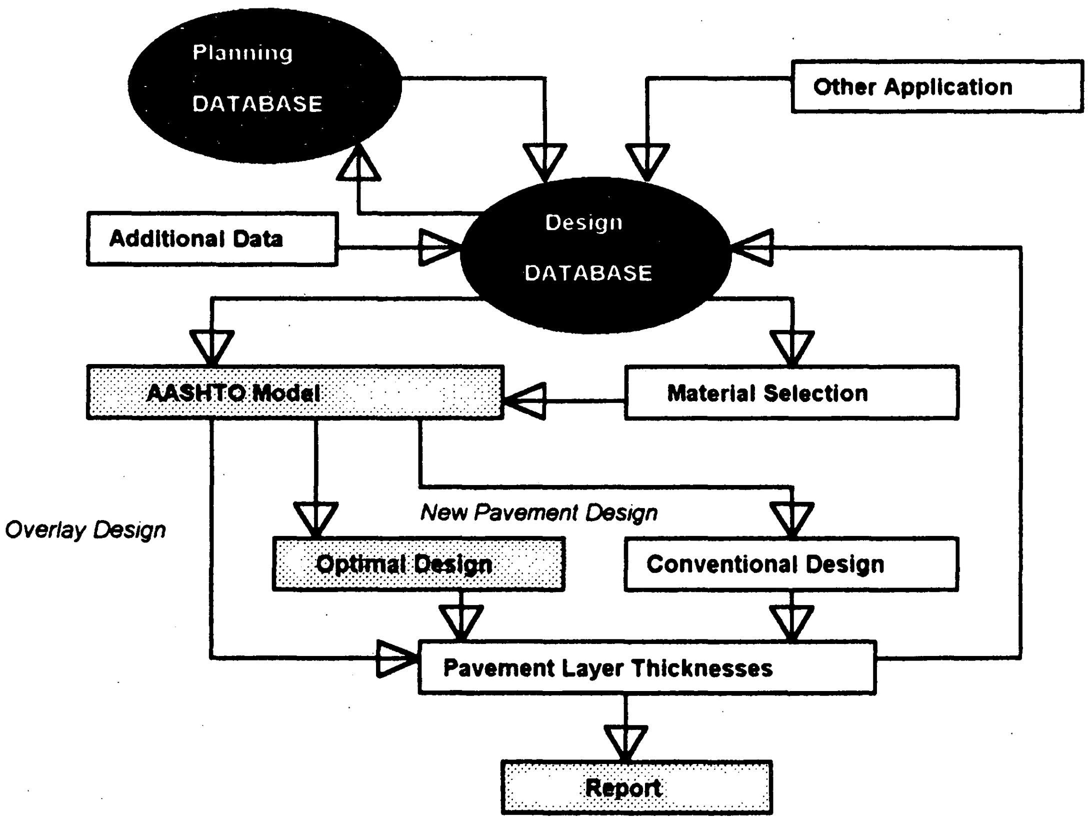


FIGURE 2 Data flow diagram for design system.

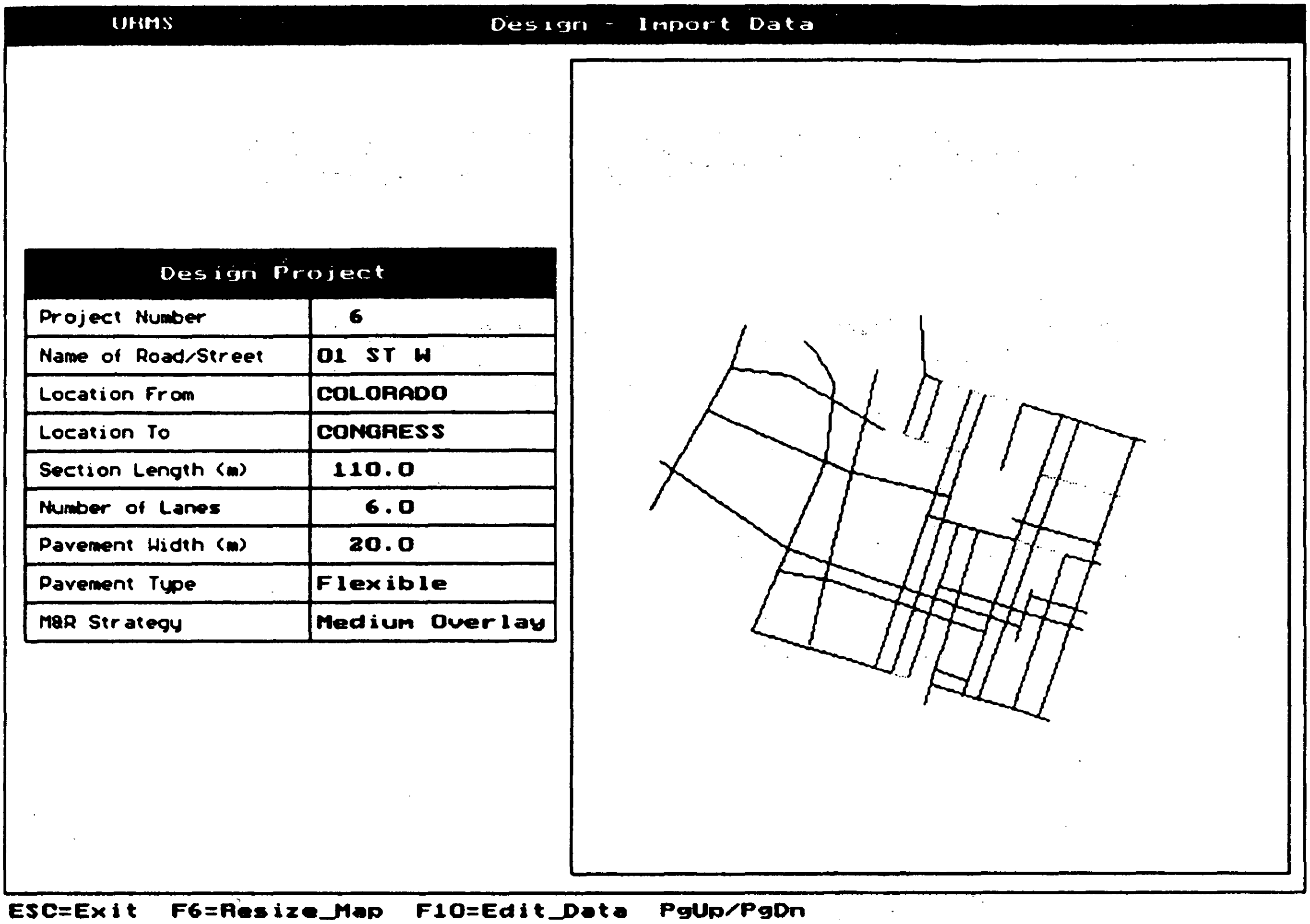


FIGURE 3 Main screen for data import.

map, but those selected for design can be identified in the left box by pressing the page up and page down (PgUp/PgDn) keys. Since the network-level data base does not store all of the information needed for the project-level design subsystem, additional data must be entered by the user for each section. These data are described in detail in the AASHTO guide (*2*) and are tabulated in the URMS user's guide (*5*).

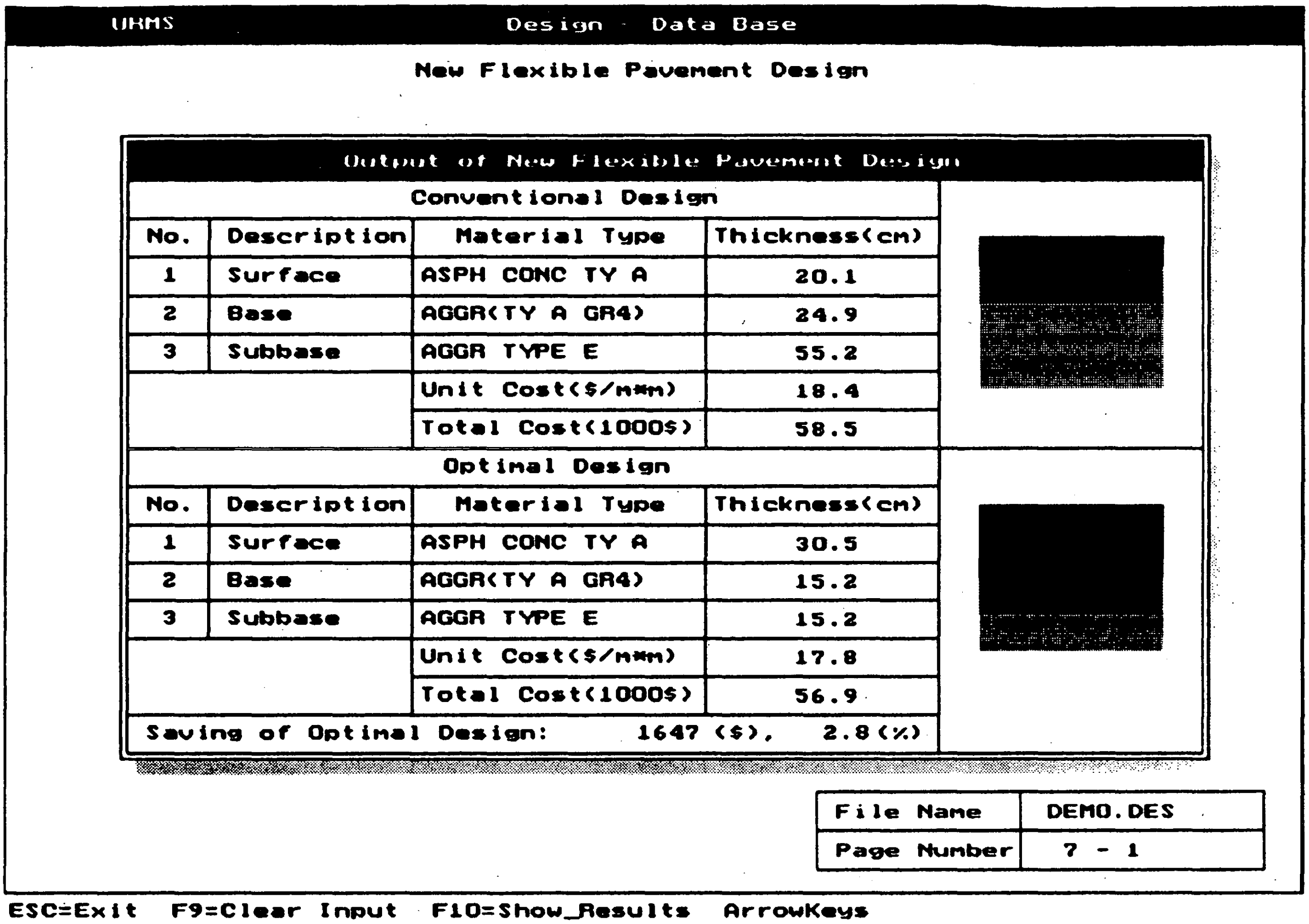
The main advantage of the design subsystem compared with other design programs such as DNPS86 (*6*) is that both the selection of materials and the determination of optimal thicknesses for the pavement structure are incorporated into the subsystem. Up to seven types of material for each layer can be entered.

Figure 4 shows an example for new flexible pavement design. Both the conventional and optimal design results are presented. The scale diagram of the layer thicknesses for each solution is displayed accordingly. The optimal design alternative gives the noninteger optimal solution (the least-cost solution) to the problem, whereas the conventional design gives solutions by taking the user's input into account. The user can enter one or two of the layer thicknesses and the program will compute the other(s). For example, given the thickness of the surface, the program then calculates the thicknesses of the base and subbase courses, or given the thicknesses of the surface and the subbase, the program calculates the thickness of the base course. Because this program uses an embedded linear programming model, the optimal design produces only the noninteger solutions. The noninteger solution is economically correct, but it may not be accepted in practice. This manual design function provides more flexibility to the user in pavement design.

MAINTENANCE SUBSYSTEM

The objective of the maintenance subsystem is to provide the user with a simplified expert system tool rather than an end product expert system for routine pavement maintenance. Since the repair method for a specific distress may vary from city to city, it is impossible to build an expert system for every city without changing the knowledge base. The simplified expert system aims to provide a tool for engineers with little knowledge of expert systems to build their own expert systems without any coding.

An expert system is a computer program that simulates the thought process of human experts to solve complex decision problems in a specific domain. Expert systems can increase the probability, frequency, and consistency of making good decisions, help distribute human expertise, and facilitate real-time, low-cost, expert-level decisions by the nonexpert. Expert systems are suitable



Conventional Design			
No.	Description	Material Type	Thickness(cm)
1	Surface	ASPH CONC TY A	20.1
2	Base	AGGR(TY A GR4)	24.9
3	Subbase	AGGR TYPE E	55.2
		Unit Cost($/m*m)	18.4
		Total Cost(1000$)	58.5
Optimal Design			
No.	Description	Material Type	Thickness(cm)
1	Surface	ASPH CONC TY A	30.5
2	Base	AGGR(TY A GR4)	15.2
3	Subbase	AGGR TYPE E	15.2
		Unit Cost($/m*m)	17.8
		Total Cost(1000$)	56.9
Saving of Optimal Design:		1647 ($),	2.8 (%)

FIGURE 4 Output screen for design subsystem.

for those problems that are well-bounded and focused, not numerically involved, and algorithmic in nature.

Routine pavement maintenance is an important daily task in public works departments. Correct and effective repair of pavement distresses not only can reduce the pavement deterioration rate to save millions of dollars for pavement rehabilitation but can also save vehicle operation costs such as tire wear, vehicle maintenance and repair, and travel time and can possibly even prevent some traffic accidents.

Routine maintenance is a suitable area for the application of expert systems. The major task of routine maintenance is to repair pavement distresses. Pavement repair ranges from crack sealing to full-depth repair. In the selection of a repair method for a specific pavement distress, many variables such as distress type, density, severity, traffic, climate, materials, roadbed soils, and others may be taken into account. There is no quantitative method that can be used to solve this problem. Much is done by intuition and experience. The use of expert systems can help to improve routine maintenance activities.

Much work has been done in the development of expert systems for pavement maintenance (*7–9*). Most applications were developed by using expert system shells such as EXSYS, VP EXPERT, and NEXPERT. Although these shells greatly reduce the time and effort required to build an expert system in a specific domain, they still require training of maintenance technicians or engineers before they can develop their own expert systems.

Since the knowledge bases for most of these shells are built by using text-based rules, modification of the knowledge base requires specially trained personnel. It is desirable to develop a simplified expert system developmental tool so that engineers and technicians with little knowledge of expert systems can build, modify, and expand their own expert systems for selecting effective distress repair methods without any coding.

Design of Expert System Tool

Assume that the repair method for a distress type depends on m variables and that each variable can be divided into n levels; then there will be a maximum of m^n combinations. For some combinations there may be more than one repair method, so at least m^n repair methods for that type of distress can be defined. For example, let m equal 3 and n equal 3; then there will be at least 27 possible repair methods. In practice, for most cases three variables with three levels, giving at least 27 repair methods for each distress, are sufficient (*7,10*).

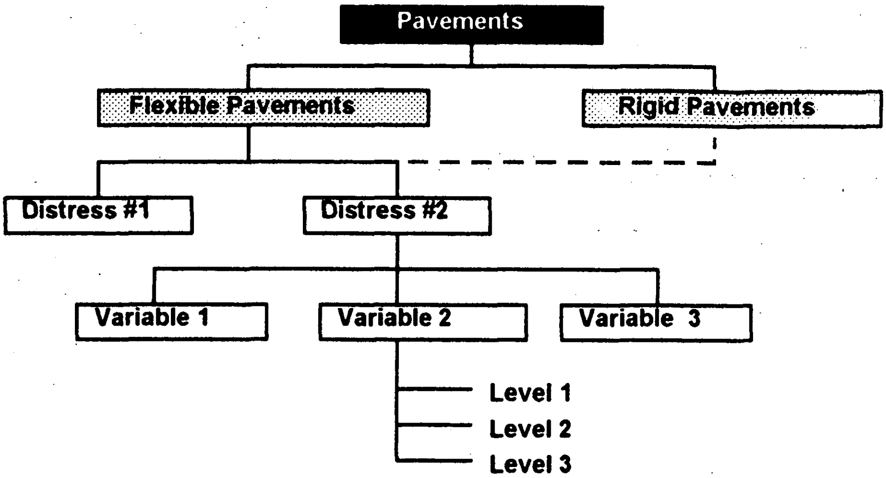


FIGURE 5 Variable hierarchy of knowledge base.

Although the number of variables and the number of levels of each variable can be changed in the computer program without any difficulty, the tool developed in this study considers three variables and three levels for each variable.

Figure 5 shows the hierarchy of the variables and the levels of each variable used to define the structure of the knowledge base. Pavements are divided into flexible pavements and rigid pavements. Distress types are identified for each pavement. A knowledge base is constructed as a random access file. Each distress is a record in the file. Basically, a record is composed of two arrays; one stores the variables, the levels of each variable, and the description of each level, whereas the other one stores the distress repair methods. A record can handle a maximum of 27 rules, as in the case of a text-based knowledge base.

A decision tree is built for each distress type. The structure of the tree may differ from one distress type to another, depending on the number of variables and the number of levels of each variable specified for the distress.

Because the knowledge base is a random access file, all the repair methods related to a distress type are stored in the same record, and the computation is done in random access memory, the size of the knowledge base has little influence on the time spent searching for a conclusion.

Use of Expert System Tool

The simplified expert system tool was developed primarily for selecting pavement distress repair methods, but it can also be used for pavement preventive maintenance and network-level M&R strategy assignment. The process of building the knowledge base is simple. First, the user defines the variables, defines the levels of

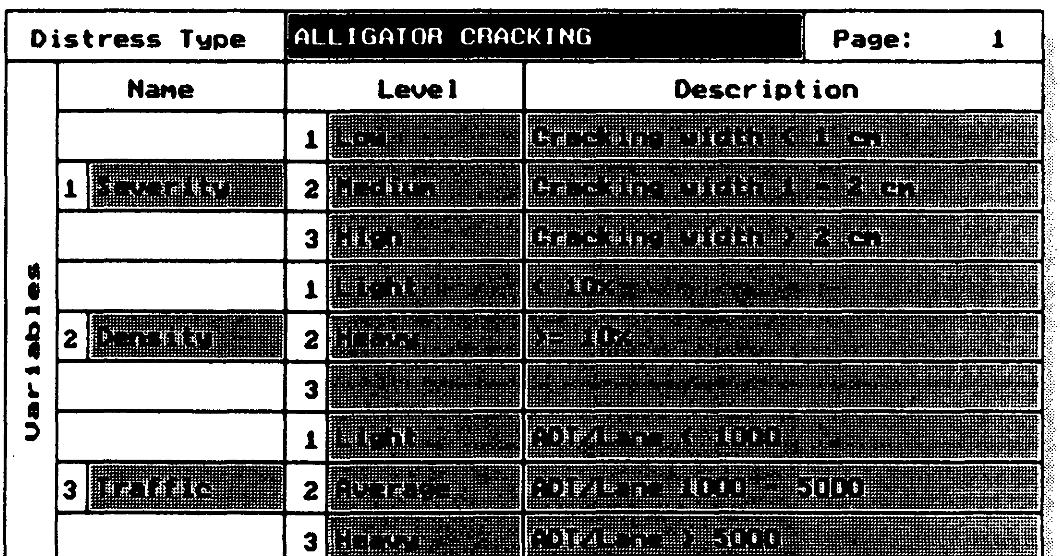


FIGURE 6 Define variables and levels for and describe each variable.

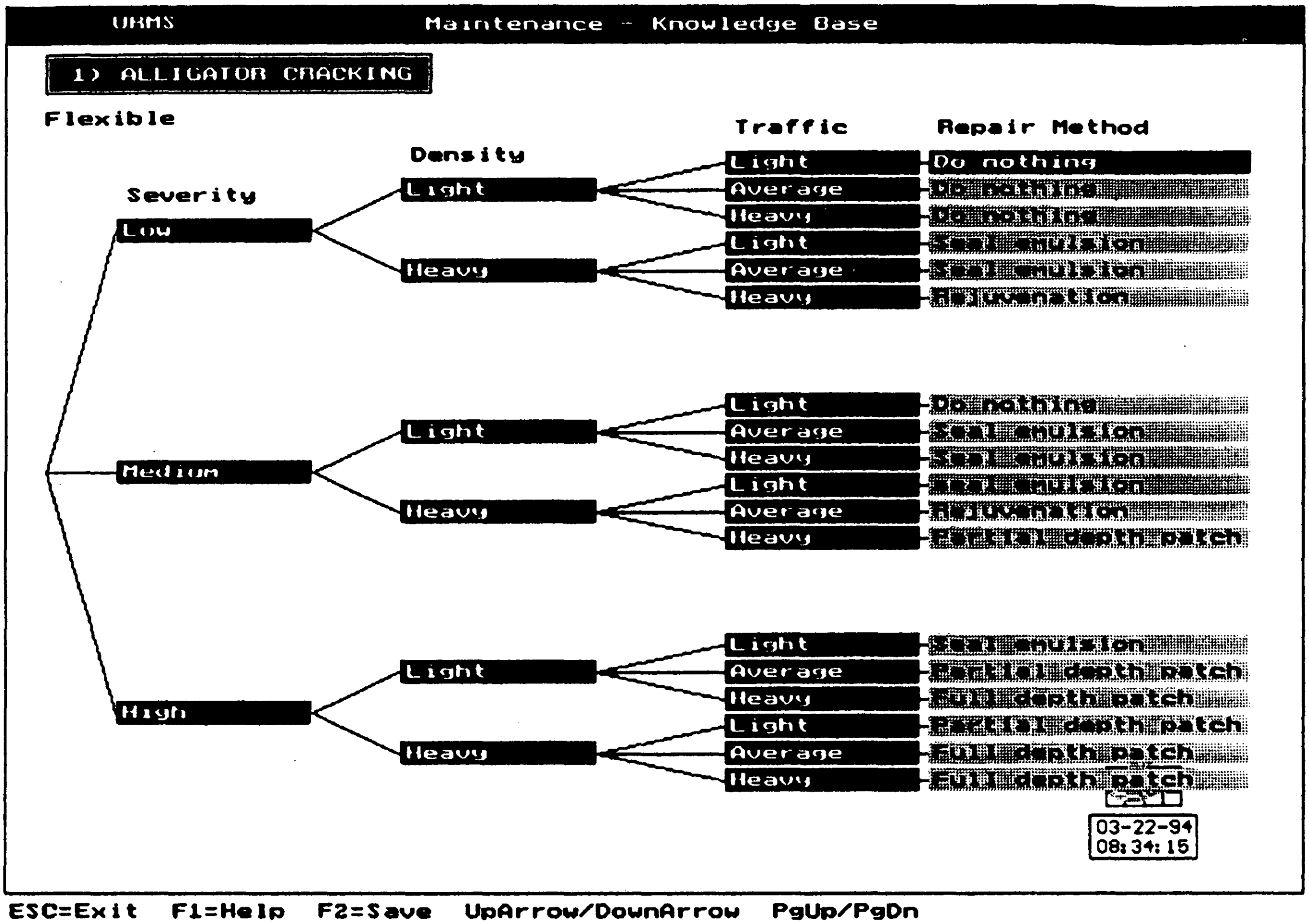


FIGURE 7 **Define repair methods.**

Flexible Pavement 1) ALLIGATOR CRACKING			
Severity ?	Low	Medium	■ High
Density ?	Light	■ Heavy	
Traffic ?	Light	■ Average	Heavy
Recommended Repair Method: Full depth patch			

FIGURE 8 **Consultation menu.**

each variable, and describes each level as shown in Figure 6, and then the user specifies the repair method for each variable combination in the decision tree as shown in Figure 7.

Once the development of the knowledge base is completed the expert system is ready and consultation can be conducted. To get the recommended distress repair method the user selects one of the levels of each variable as shown in Figure 8. The recommended repair method is then displayed at the bottom of the consultation box. The tracing of the decision can also be seen in the decision tree.

If there is more than one distress type in the area each distress type is run separately and the distress repair method that is suitable for all of the distress types is selected. There is no priority ranking procedure for prioritizing the distress repair methods in the current version of the program.

The program can convert the decision trees to rule-based knowledge. This option provides a useful method for knowledge communication among expert systems. For example, the rules converted from this simplified expert system can be exported to VP EXPERT or other expert system shells with only a few additional lines of coding.

CONCLUSIONS

The project-level design and maintenance subsystems of URMS are described in this paper. The advantage of the design subsystem is that both the selection of materials and the determination of the optimal thicknesses of pavement structures are incorporated in the subsystem. The advantage of the maintenance subsystem is that the simplified expert system tool can be used to build expert system applications for routine pavement maintenance without any coding. Both subsystems are integrated into the network-level URMS with a graphical user interface, but they can also be used as stand-alone programs.

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