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Paper 64

An Expert System for Pavement Management in Urban Road Networks

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Abstract

This paper presents an expert system for maintenance management of road pavements with emphasis to urban and local streets. The knowledge acquisition was based on interviews, questionnaires, and system evaluation with maintenance expert engineers from municipal agencies. The system includes functions for maintenance priority setting among road sections, feasible treatment assessment in each case, and maintenance planning in a road network. Maintenance priorities are set using a scoring model with decision parameters appropriately weighted. Feasible treatments are determined based on pavement condition and other factors that influence performance deterioration. Decisions for maintenance planning are based on priority ranking, cost and effectiveness characteristics of feasible treatments, and existing budget constraints. The system has been successfully evaluated with actual data from the road network of the City of Patras.

Keywords: pavement, maintenance, management, expert system, knowledge-based system, decision making.

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1 Introduction

Pavement management systems (PMS) have undergone extensive research, development, implementation and testing over the past four decades, as indicated by the number of papers, reports and books published. The primary objectives of pavement management systems are to (1) evaluate pavement conditions and predict future deterioration, (2) determine alternative maintenance or rehabilitation strategies for given roadway sections, (3) recommend “best” or “most cost effective” strategies, and (4) develop and evaluate network-wide maintenance or rehabilitation plans considering system performance goals and budget allocations over a planning horizon.

Expert systems (ES) have been recognized as a significant breakthrough in software technology. The principal distinction between expert systems and conventional algorithmic programs lies in the use of knowledge. An expert system separates the program into an explicit knowledge base describing the problem solving strategy and a control program or inference engine that manipulates the knowledge base. Considering the complexity of the typical pavement management problem and the difficulty to establish realistic constituent models and parameter assessment, the experience of maintenance professionals may be invaluable towards the development of new or the enhancement of existing algorithmic PMSs. Further, as flexibility in the design of pavement management systems is essential, expert systems seem to be appropriate implementation solutions, in this regard, for a PMS.

Existing expert-system based pavement management systems have primarily been directed to deal with pavement management in highway and arterial road networks. Road segments of different categories present general similarities in terms of design, construction, operation and maintenance characteristics. However, pavement condition performance and maintenance actions may vary between urban and inter-urban urban roads (or arterial and local roads) due to a number of reasons. In particular, urban (or local) roads may present:

- lower design standards,
- lower construction standards and/or quality of construction,
- extraordinary traffic composition and load patterns (e.g., increased bus percentage),
- complex dynamic loading (e.g., frequent stop-go traffic),
- lower travelling speeds,
- frequent utility network cuts that wound the pavement integrity.

With respect to the latest factor, it is known that urban roads commonly integrate a number of utility lines running parallel to and across the roads. Utility cuts are then necessary for electricity, fiber optics and telephone lines, water and drainage pipelines. Constructing and maintaining these utility lines requires the road pavement be dug. Patching, a typical treatment of local distresses in urban roads, results in a noticeable decline of both the riding quality and the structural integrity of the pavements. As a result of the above, urban road pavements encounter substantial deterioration over time.

The aim of this paper is to present an expert system which can assist engineering decision-making with regard to urban road pavement deterioration and provide proposals for best or most cost effective maintenance and rehabilitation actions. The proposed expert system considers a number of parameters including:

- parameters associated with current pavement condition (e.g., distress type, severity, and extent),
- pavement design and operating characteristics which typically determine the deterioration rate in time (e.g., pavement age, soil type and conditions underneath the pavement - possible cavities, traffic loads, environmental conditions),
- treatment characteristics (e.g., treatment type, distress-treatment suitability matrix, treatment effectiveness and cost).

The pavement deterioration types that are considered in this study represent the major distresses appearing in a typical urban road network. In accordance with the development aims and objectives, the expert opinion that is being represented in the study has been narrowed to that provided by expert engineers in road maintenance and management of the City of Patras.

2 Previous research

Among several pavement management systems reported in the literature, there have been systems that are developed employing expert systems. An expert system simulates human thought and follows the line through a mechanism of inference that analyzes the input data and makes decisions to solve a problem or provide advice. Its development uses symbolic rules to represent a special knowledge on the particular subject area. These rules, which are structured in an "if-then" form, show some attractive features like explicit definition, uniformity and ease of the explanation.

Expert systems have been successfully applied for pavement management. Most existing systems, such as Rose [3], Preserver [4], Erasme [5], Expear [6], Pavement Expert [7] and Paves [8], were developed for flexible highway pavements and utilize the surface distress condition to obtain information, draw conclusions, and make maintenance and rehabilitation recommendations. PAVER [9] and AIRPACS [10], were developed to evaluate the condition and provide maintenance and rehabilitation decisions primarily for airfield pavements. Finally, the system presented in [11] combines an expert system for maintenance and rehabilitation selection and an integer-programming model for optimal resource allocation among sections. An overview and comparative evaluation of existing expert systems can be found in [12].

3 The proposed system

The proposed expert system consists of three decision modules. The first aims to provide maintenance priorities among road segments. To this respect, current pavement conditions, the traffic loads and other operating characteristics are considered. A weighted, utility-type of function is employed to indicate the maintenance priority Parameter weights and section grading were set by experience and evaluated by experts on the basis of results from actual data entries.

The second module explores all applicable treatments in each section considering the specific conditions in it. A rule-based expert system has been developed to represent the expert's opinion under each possible condition. The system further sorts these treatments in each case according to their effectiveness/cost ratio. Effectiveness is considered in terms of the expected duration of each treatment until another treatment becomes necessary.

The third module considers the maintenance priority list and the most cost-effective applicable treatments provided by the previous modules, calculates the cost of the necessary maintenance works in each section and for the whole network and provides a network-wide maintenance and rehabilitation plan considering also any budgetary constraints.

The system has been implemented in Ms-Excel. Although there are several platforms for expert-system implementation, the proposed system includes modules of different application types. The software selection was based on its two main advantages, user acquaintance and friendliness as well as the capability to develop all individual modules in a single software (the cost values for maintenance works are also registered in Excel form). On the other hand, the implementation in the selected software presents some scalability difficulties.

3.1 Pavement condition assessment and priority setting

Among all possible pavement distress types that may appear in a road network, the most frequent or important ones (in terms of frequency and/or impact to road functionality and safety) in a typical urban network are those presented in Figure 1 (appropriately categorized).

A three-level categorisation is employed for each distress type to assess its severity and impact on road functionality and safety:

- a low level indicates a distress that is now emerging with no observable consequence to safety,
- a medium level indicates an observable distress that may need proper attention,
- a high level indicates a fully developed distress with a major consequence on safety that requires immediate remedy.

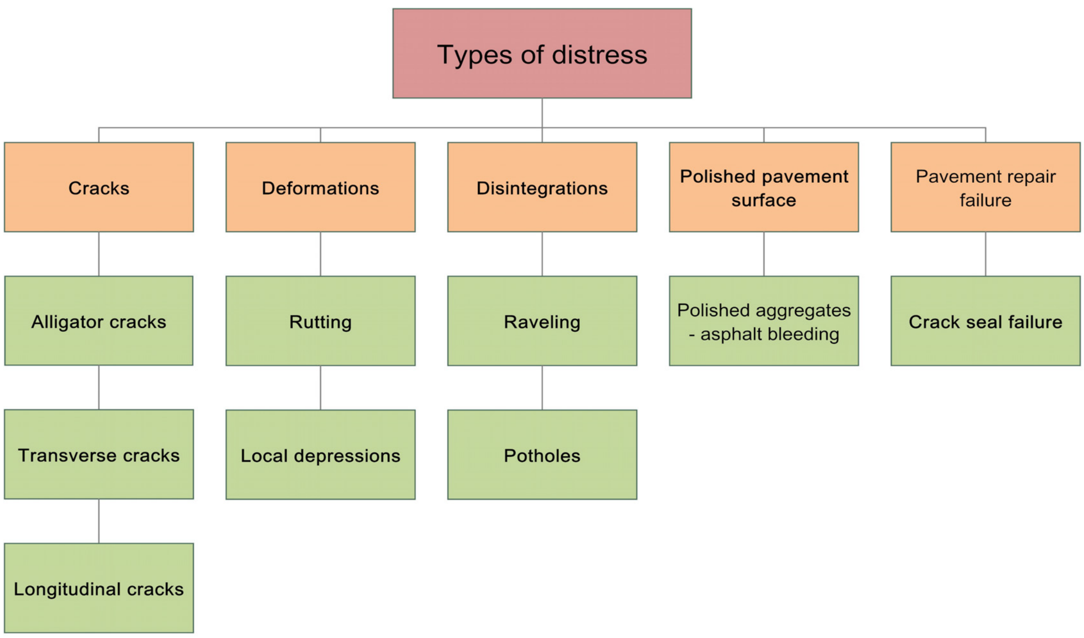

Figure 1: Typical distresses in urban road networks

The proposed system incorporates a number of attributes that are considered important in the decision making process by maintenance engineers. Such attributes include pavement distress characteristics (type, severity and extent) which directly affect road operability and safety, traffic loads, foundation soil characteristics, environmental conditions, and pavement age. The above characteristics not only reveal the current pavement condition but also indicate the expected future pavement performance and deterioration rate. The weights given to the pavement condition and deterioration factors have been set by experience and are shown in Figure 2.

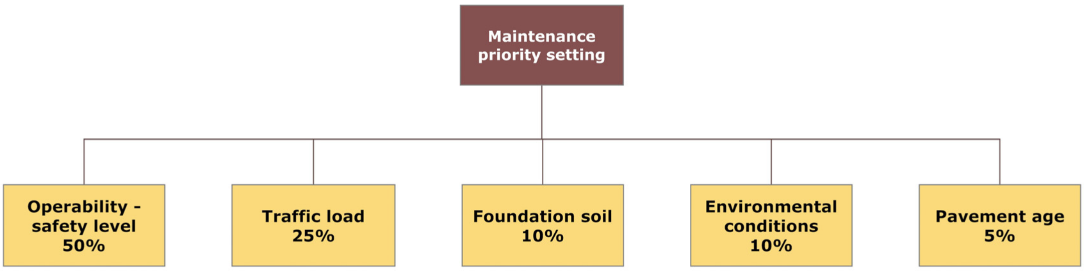

Figure 2: Importance weights of pavement condition influencing factors

Each influencing factor has been further broken-down to its constituent elements and relative weights have been set as shown in Table 1. The decision criteria for distress severity characterization were set following the instructions from the "Manual for inspection and classification of pavement distresses" of the Hellenic Ministry of Public Works [13]. Maintenance and rehabilitation cost estimates were derived from the same source. In addition, personal interviews were conducted and appropriately developed questionnaires were distributed to expert engineers of the Municipality of Patras who are in charge of managing the urban road network of the city. The information gathered through these means was utilized in the development of the priority setting module and the assessment of feasible treatments described below.

Following appropriate pavement inspection, the above characteristics are assessed for each road section under consideration. A weighted, utility-type of function is employed to indicate the maintenance priority. In this function, each parameter is considered with the corresponding weight (from Table 1). For each road section, every parameter is given a value (based on the inspection results) within a specified range of values or among qualitative assignments. Following a total grade (the priority index PI) is calculated and assigned to each section which indicates the maintenance priority. If multiple distresses appear in a pavement section, these distresses are sorted in descending order of their impact on operability and safety. The total priority index for such a section results from the sum of PIs for all individual distresses except that the contribution of any subsequent distress is considered by a reduced percent of 50%. In particular the first distress is considered with coefficient 1.0, the second with 0.5, the third with 0.25, and so on.

Attribute	Weight	Options	Weight
Distress type (severity, extent, and location)	0,50(*)	1. Alligator cracks	0,09
		2. Transverse cracks	0,03
		3. Longitudinal cracks	0,02
		4. Rutting	0,12
		5. Local depressions	0,10
		6. Raveling	0,06
		7. Potholes	0,38
		8. Polished aggregates	0,10
		9. Crack seal failure	0,10
Traffic load	0,25	1. Low	0,15
		2. Medium	0,35
		3. High	0,50
Foundation soil	0,10	1. Earthy	0,55
		2. Rocky	0,45
Environmental conditions	0,10	1. Lowland	0,45
		2. Mountain	0,55
Pavement age	0,05	1. Less than 20 years	0,55
		2. More than 20 years	0,45

(*) The weights for distress type are multiplied: a) by 1,7 or 1,3 to account for high or medium severity respectively and b) by 1,7 to account for wide extent.

Table 1: Parameter weights for maintenance priority setting

3.2 Assessment of applicable maintenance treatments

The second module explores all applicable treatments in each section considering the specific conditions in it. A rule-based expert system has been developed to represent the expert's opinion under each possible condition. The system employs forward reasoning as an inference engine, may be depicted in a decision tree form (Figure 3). In each level of the decision tree, a single parameter is examined. Depending on the "value" of the parameter, acceptable maintenance solutions proceed to the next level while ineffective treatments are dropped. The system consists of 6.480 “if-then” rules.

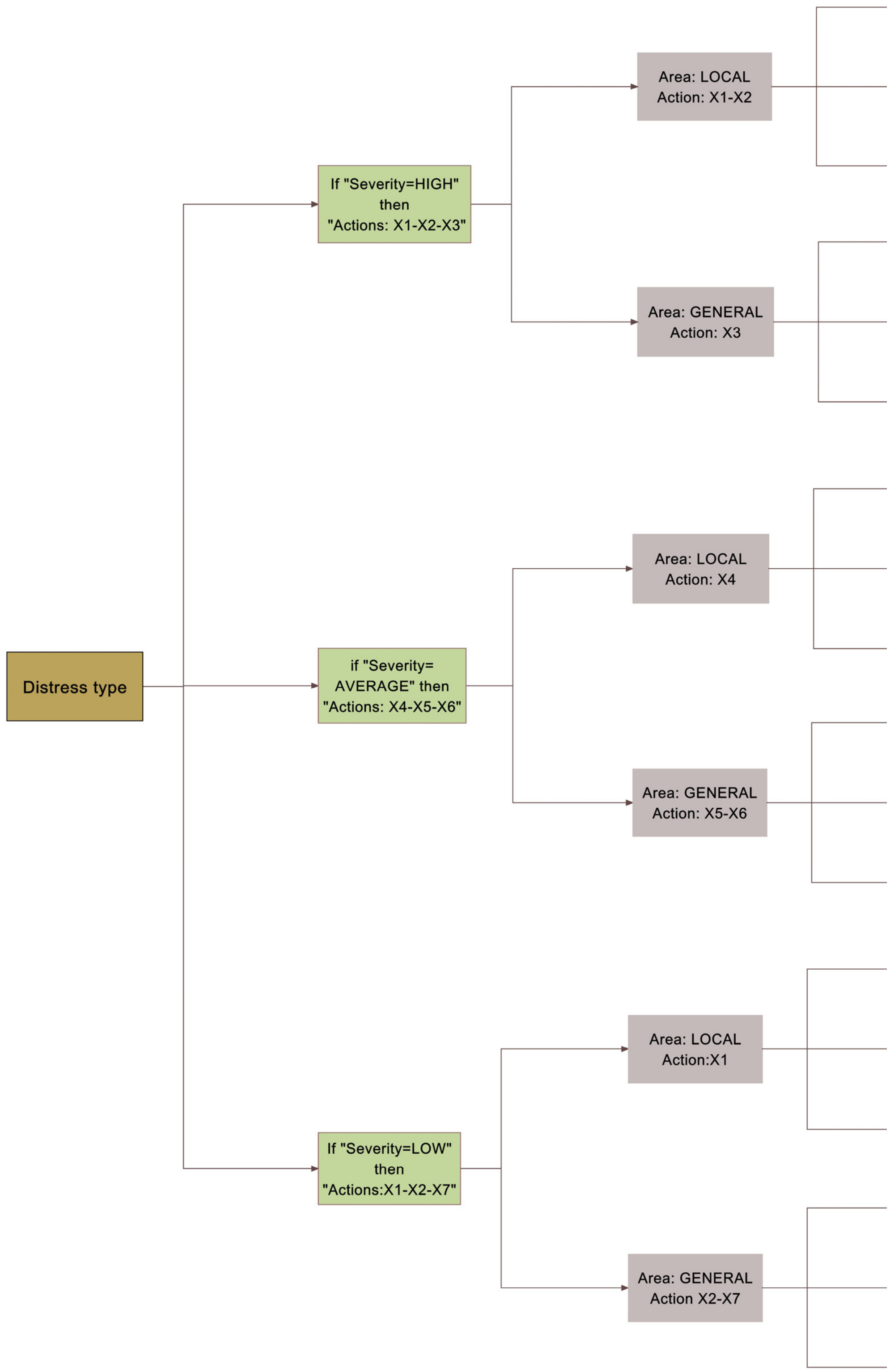

Figure 3: Decision-tree structure for feasible maintenance assessment

Besides identifying applicable treatments, the system also sorts these treatments (in each case) according to their effectiveness/cost ratio in order to propose the optimal maintenance treatment (Figure 4). Effectiveness is considered in terms of the expected duration of each treatment until another treatment becomes necessary.

3.3 Network-wide maintenance selection

Because available resources for pavement maintenance and rehabilitation are typically limited, the third module aims to provide decision support regarding the pavement sections that require prompt attendance and the most appropriate maintenance and rehabilitation action. This module considers the maintenance priority list and the most cost-effective applicable treatment for each section. Based on these inputs, it proposes the segments to be maintained and the type of intervention that fit within the available budget, providing also cost estimates of the necessary maintenance works in each section and for the whole network. The cost calculations are based on current work and material pricing provided by the Ministry of Public Works in the form of cost tables which are regularly updated.

4 An application case study

An application case study from the road network of the City of Patras is presented to illustrate and evaluate the system structure, application and results. Table 2 presents (a snapshot of) the required input information from ten pavement sections of the road network. Most of them present a single distress type while three of them (#2, #9, #10) have multiple distresses.

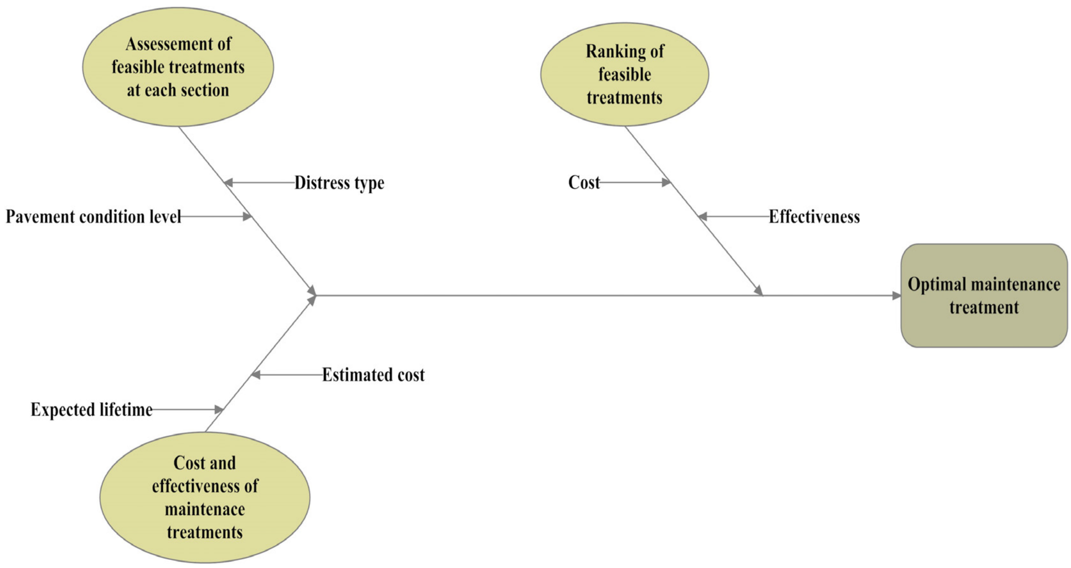

Figure 4: Optimal maintenance treatment assessment

	Types of distress	Road sections for restoration 1	2	3	4	5	6	7	8	9	10
	Cracks										
1.	**Alligator cracks**	1								1	
	Distress severity	2								3	
	Distress extent	2								2	
	Area of damage (m2)	85								250	
2.	**Transverse cracks**				1						1
	Distress severity				2						2
	Distress extent				1						1
	Area of damage (m2)				50						50
3.	**Longitudinal cracks**			1							
	Distress severity			3							
	Distress extent			1							
	Area of damage (m2)			75							
	Deformations										
4.	**Rutting**						1				
	Distress severity						2				
	Distress extent						1				
	Area of damage (m2)						90				
5.	**Local depressions**					1					
	Distress severity					1					
	Distress extent					1					
	Area of damage (m2)					120					
	Disintegrations										
6.	**Raveling**		1								1
	Distress severity		3								2
	Distress extent		2								1
	Area of damage (m2)		150								100
7.	**Potholes**		1							1	
	Distress severity		2							2	
	Distress extent		1							1	
	Area of damage (m2)		5							20	
	Polished pavement surface										
8.	**Polished aggregates - asphalt bleeding**							1			
	Distress severity							2			
	Distress extent							1			
	Area of damage (m2)							50			
	Pavement repair failure										
9.	**Crack seal failure**								1		
	Distress severity								1		
	Distress extent								1		
	Area of damage (m2)								40		
	General information of road sections										
	Traffic load	1	1	1	2	3	2	2	2	3	1
	Foundation soil	1	1	1	1	1	1	1	1	1	1
	Environmental conditions	1	1	1	1	1	1	1	1	1	1
	Pavement age	2	2	2	2	2	2	2	2	2	2

Table 2: Input data sheet for case-study road sections

The results of the maintenance priority settings are presented in Table 3. The highest maintenance priority is given to Section #9 which presents medium severity potholes and high severity alligator cracks. Section #5 is ranked third mainly due to high traffic loading.

Table 4 illustrates the sections that will be maintained (in order of priority), the proposed maintenance in each case, and the cost distribution for an assumed budget constraint of 7.000 €.

Road section	Priority index	Priority ranking
Section #1	0,259	8
Section #2	0,530	2
Section #3	0,177	10
Section #4	0,230	9
Section #5	0,298	3
Section #6	0,288	5
Section #7	0,275	6
Section #8	0,260	7
Section #9	0,683	1
Section #10	0,289	4

Table 3: Priority ranking for the application case study

Priority	Section no	Feasible treatments	Estimated cost (€)	Cumulative cost (€)
1	9	Local purge with squaring and laying of hot or cold asphalt, preceded by adhesion, and leveling with a 4-5 cm layer	2943,00	2943,00
2	2	Local purge with squaring and laying of hot or cold asphalt, preceded by adhesion, and leveling with a 4-5 cm layer	1689,50	4632,50
3	5	Local purge without squaring and laying of hot or cold asphalt, preceded by adhesion	482,40	5114,90
4	10	Milling in layers and leveling with a 4-5 cm layer	1638,00	6752,90

Table 4: Maintenance selection and cost calculation at a network level

5 Conclusions

Pavement management systems (PMS) are used to provide proposals for “best” or “most cost-effective” network-wide maintenance and rehabilitation strategies over a planning horizon. Considering the complexity of the typical pavement management problem and the difficulty to establish realistic constituent models and parameter assessment, the experience of maintenance professionals may be invaluable towards the development of new or the enhancement of existing algorithmic PMSs. Existing research on knowledge-based pavement management systems has primarily been directed to highway and arterial road networks. Urban roads, however, presents some special characteristics that may require particular attention. Among them, pavement design and construction standards, traffic composition, pavement loading patterns, and frequent utility cuts that wound the pavement integrity can be mentioned.

The aim of the present study is to develop an expert system which can assist engineering decision-making with regard to urban road pavement deterioration and provide proposals for cost-effective maintenance and rehabilitation strategies. The proposed system considers parameters regarding distress and treatment characteristics, traffic loads, foundation soil type, etc.

The system consists of three decision modules. The first aims to provide maintenance priorities among road segments. To this respect, current pavement conditions, the traffic loads and other operating characteristics are considered. A weighted, utility-type of function is employed to indicate the maintenance priority. Parameter weights and section grading were set by experience and evaluated by experts. The second module explores all applicable treatments in each section considering the specific conditions in it. A rule-based expert system has been developed to represent the expert’s opinion under each possible condition. The system further sorts these treatments in each case according to their effectiveness/cost ratio. The third module calculates the cost of the necessary maintenance works and provides a network-wide maintenance and rehabilitation plan taking into account any budgetary constraints.

The system has been evaluated with data from the road network of the City of Patras. Results have been appraised by expert engineers and indicate that the proposed expert system can provide a reliable tool for short-term maintenance and management decisions.

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