Expert System for Innovative Pavement Solutions

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Abstract :

The use of expert systems in civil engineering and especially in road construction has become a necessity due to the structure's specificity in dimensioning which is completely different from other structures. The parameters involved in road structure dimensioning are multidisciplinary in their values and behaviors; the road structure is complex and composed of heterogeneous materials, its behavior is unpredictable due to the nature of the soil, the influence of climate and different loads it supports. This expert system proposes different thickness, stress and strain solutions by comparing them with the allowable values based on different mechanical models and formulates the methods and data-sheets then provides choices of body composition for the road based on the new version of the Algerian pavement catalog (2003).

Key words: Flexible pavements, pavement body, artificial intelligence, expert system.

1. Introduction

The computer in its classical form has acquired a central role in most businesses and human activities. When a task is repetitive and well-defined by an algorithm, it can be entrusted to a computer.
The notion of algorithm involving a sequence is the basis of most classical programs. Artificial intelligence is the discipline which tries to understand the nature of intelligence by building computer programs imitating human intelligence.
Characterized by a large surface area, Algeria has contrasting regions in terms of topography, climate, economic and agricultural potential as well as density of population. This diversity has generated the need to travel. In our country 90% of travel and exchanges of goods is done by road, hence the need for a new coherent and pragmatic policy in regard to maintenance and modernization of the existing road network and construction of new roads.
The project of the Catalog "New Pavement dimensioning" is important, since it is a recent document that summarizes the results of the behavior of materials that have allowed rational dimensioning of structures.
Our work is based on this document which is the result of close collaboration between Algerian and French experts and researchers (ENPC, SETRA and LCPC).
The computer tool used for the validation of this work is the expert system generator GURU.
The approach in the implementation of expert systems is based on the specific geological and

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climatic conditions of the country as well as resource materials available for each region. It gives the users the choice among several alternative dimensioned structures according to the local and regional techno-economic data of the project.

2. Flexible Pavement Dimensioning Methods

2.1. Principle of Design

The role of pavements is to distribute the pressure exerted by the tire to bring it to a level compatible with what can be supported by the ground-support. This level of stress is evaluated by a mechanical model of the pavement, which the researchers try to develop, to make it more representative of physical reality, especially as the theory requires many simplifying assumptions. The pavement design is to meet the following two points: lower cost and optimal conditions of comfort and security. To do so, there are two very different approaches to dimensioning the pavement: one is empirical and another theoretical. The application of a repeated rolling load on foundation soil causes bending strains of the structure layers. The latter leads to compressive stresses perpendicular to the load and tensile stresses at the base layers of the foundation [1].

This system consists in developing methods and data sheets from the Algerian catalog of new pavements, as well as offering suggestions and choices of body composition for the road. This proposal is based, of course, on the mechanical characteristics of the foundation soil (bearing capacity, composition, sensitivity to water, frost, thaw ...) [2] [3], types of loads and availability of materials around the project site. The implementation of such a system will provide a significant gain in computing time for engineers and owners to avoid taking costly bad decisions.

2.2. The parameters affecting the dimensioning of pavement

The difference between these models lies in the assumptions, including the adopted approach and the mechanical behavior of materials of pavements and soil-foundations [7]. In addition, the other parameters affecting the dimensioning of pavements are:

-The ability of the pavement layers to bear and spread loads,

-Soil-foundation sensitivity to water,

-The effect of temperature (season) and freezing-thaw cycles.

2.2. Rolling load damages

Damages caused by heavy loads on the pavement surface are of various natures:

1 - The subgrade layer composed of untreated materials, records on each passage of a load a permanent strain versus applied vertical stress. The accumulation of strains, at least for traditional pavement with treated foundation layer with hydraulic or hydrocarbon binders are sufficiently low on the vertical support so that permanent deformations are moderate.

2 - The road structure with bonded layers bends at each load passage. This bending causes, at the base of the road structure, tensile stresses; the repetition of these stresses leads to an accumulation of fatigue damage which ultimately causes the breakdown of the road (cracks).

3 - The pavement (surface layer) under rolling load leads to damages of the surfacing, which becomes slippery (tangential forces) or caused significant rutting (creep).
One of the tools implementing these approaches is the software ALIZE, developed by LCPC-SETRA. ALIZE is a computation software tool for stresses created by road traffic on pavement structures [8].

3. Expert System

Expert system is a rational approach to pavement design, in the interests of realizing a uniform road network. It is a coherent method, based on the computation of the resilient stresses and strains in road structure. The design is carried out by comparing these calculated values in all the layers, to the admissible stresses and/or strains values which are evaluated according to the fatigue characteristics of the materials and their rutting behavior caused by the untreated materials and soils. In addition, it takes into account the cumulative traffic particular to the pavement.

3.1. General structure of an expert system

An expert system is generally composed of three modules (Figure. 1):
a) The Knowledge base is given in declarative form, its function is to accommodate the specific information of the field of application. It is divided into two parts:
-Database: the set of facts defining the problem to the system, as well as all the facts deduced by the system during the progression of reasoning.
-Knowledge base: proper, that which gathers together all of the information provided by the expert system on a specific domain.
b) The inference engine: is the central part of the expert system, designed as a rather general program that exploits the knowledge base by considering it as data (and therefore subject to change).
It is software responsible for exploiting given knowledge and for making deductions. It gives the impression that the expert system reasons. These rules take the form of: ‘IF’ premise ‘THEN’ conclusion.

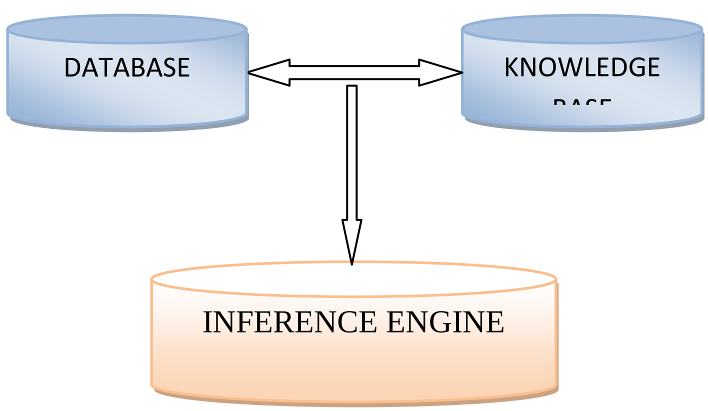


Figure 1. Expert system structure

3.2. Development tools

Artificial intelligence (AI) aims to make computers smart. A fundamental aspect of intelligence is the ability to understand and respond to questions raised by humans in natural language.
A second aspect is the ability to reason using facts, propositions and relationships to solve problems. The tool used for the development of our prototype assistance system for the choice of pavement is the Guru System.
Building an expert system with Guru requires the construction of a rule base. This base consists of rules from expert reasoning knowledge on how to solve a typical problem.
The Guru module is optimal for the construction of expert systems. This is due to its synergistic integration with all classical modules of professional computing [5].

3.3. Architecture of GURU expert system

The database is all the information available during the analysis of a particular problem.
The knowledge base consists of a set of 'IF' … 'THEN' ... describing ways known to the expert to analyze the information from the database (Figure. 2). The 'IF' part of the rule is generally named 'condition'.
The inference engine is the reasoning program responsible for situation assessment as described in the knowledge base, and triggers actions associated with each situation. A basic evaluation / trigger treatment done by the inference engine is called an inference.

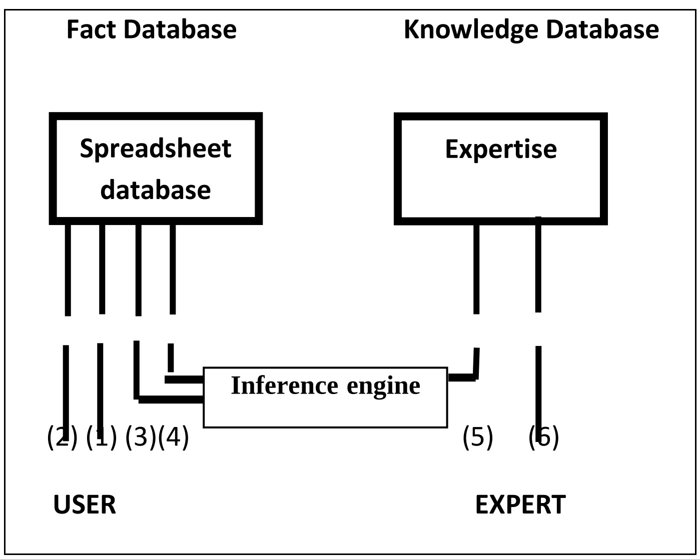


Figure 2. GURU Architecture

The user acts on the database by introducing the problem hypothesis (1) and reading the results (2). The user has access to all the tools exploited by the expert system. The expert acts on the knowledge base by introducing his or her own experience (6). The inference engine uses the expert's knowledge (5) and information from the database (3) to complete the database with facts obtained through conclusions (4).

3.4. Expert system operation

1. Forward chaining: forward chaining reasoning throughoutly covers the knowledge base and triggers all that is possible, the resulting conclusions being used immediately to trigger other rules. At the end of the course, Guru decides whether or not to undertake a new course, so that all possible rules are triggered. For a new course to be undertaken there must remain untriggered rules but also that the previous course had provided new elements, i.e. that at least one rule was triggered.
2. Backward chaining: backward chaining or inductive reasoning aims to dismantle a result; it is therefore only interested in rules that can assist it in this task. A 'Candidate Rule' is a rule that contains in its conclusion a reference to a result. This result is called during the research a goal. In backward chaining, GURU searches among all goals' 'Candidates rules' those that can be triggered.
3. Mixed chaining: it is the combination of the two types: forward and backward.

4. Implementation of Expert Systems

A tool for developing expert systems is software that facilitates the construction of expert systems. A database manager of rules is a construction and maintenance software of rules specific for each type of problems.

A generalized inference engine can reason with any rule database. Thus, the task of creating an expert system is reduced to the building its own rule database. The inference engine that can work backward reasoning is used mainly to find a goal or discover the cause of a real situation.
The formulation of the expertise can be done in several stages generating packets of rules [6].
A first rule package allows the definition of the geographical area; we have selected three major areas characterizing Algeria:

- Littoral zone
- Highland zone
- Saharan zone

A second rule package allows the introduction of the geotechnical characteristics of the foundation-soil according to climatic zones (Table 1).

Table 1. Climatic zones

Annual precipitation in mm	Climatic zones
$P > 600$	I
$350 < P < 600$	II
$100 < P < 350$	III
$P < 100$	IV

Following that and according to the road classification by climatic zones (different from geographic zones) which are four (04) are defined in function of hydrometric, as well as drainage quality (Table 2).

Table 2. Load carrying capacity classification of soil

Categories	CBR index (%) of maximal density modified PROCTOR (4 day immersion) applicable to flexible pavements
S0	> 40
S1	25 to 40
S2	10 to 25
S3	5 to 10
S4	< 5

We adopted this classification of soils for Algerian roads (Table 3). The classification contains seven (07) soil families, which are: gravel, sand, alluvium, clay, tufa, marl and silt. Each of these families is divided into further sub families, to better specify the soil [4].

Table 3. Classification of soil

Family	Nature of soil	Road classification by climatic zone					
		I and II		III		IV	
		Quality of soil drainage					
		Good	poor	good	poor	good	poor
Gravel	Clean, well, poorly calibrated	S1	S1	S1	S1	S1	S1
	Silty	S1	S2	S1	S2	S1	S1
	Clayey	S2	S3	S1	S3	S1	S1
Sand	Clean, well calibrated	S1	S1	S1	S1	S1	S1
	Clean, poorly calibrated	S2	S2	S1	S2	S1	S1
	Course, well, poorly calibrated	S2	S3	S2	S3	S1	S1
	Fine silty clayey	S2	S3	S2	S3	S1	S1
Alluvium	Slightly plastic	S2	S2	S2	S3	S1	S2
	Highly plastic	S3	S4	S3	S3	S1	S2
Clay	Slightly plastic	S3	S4	S2	S3	S1	S2
	Highly plastic	S3	S4	S2	S3	S1	S2
	Salted bottomland	S3	S4	S2	S3	S1	S2
Tufa	Encrustation	S1	S1	S1	S1	-	-
	Granular horizon	S1	S2	S1	S2	-	-
Marl	Structure	S3	S4	S2	S3	S1	S2
silt	Organic soil	S4	S4	-	-	-	-

A third rule package is designed to help decide on the choice of layers which concord with the foundation soil that is classified as one of four (04) categories, taking into account the cumulative traffic over 20 years of service (Table 4).

Table 4. Traffic classification

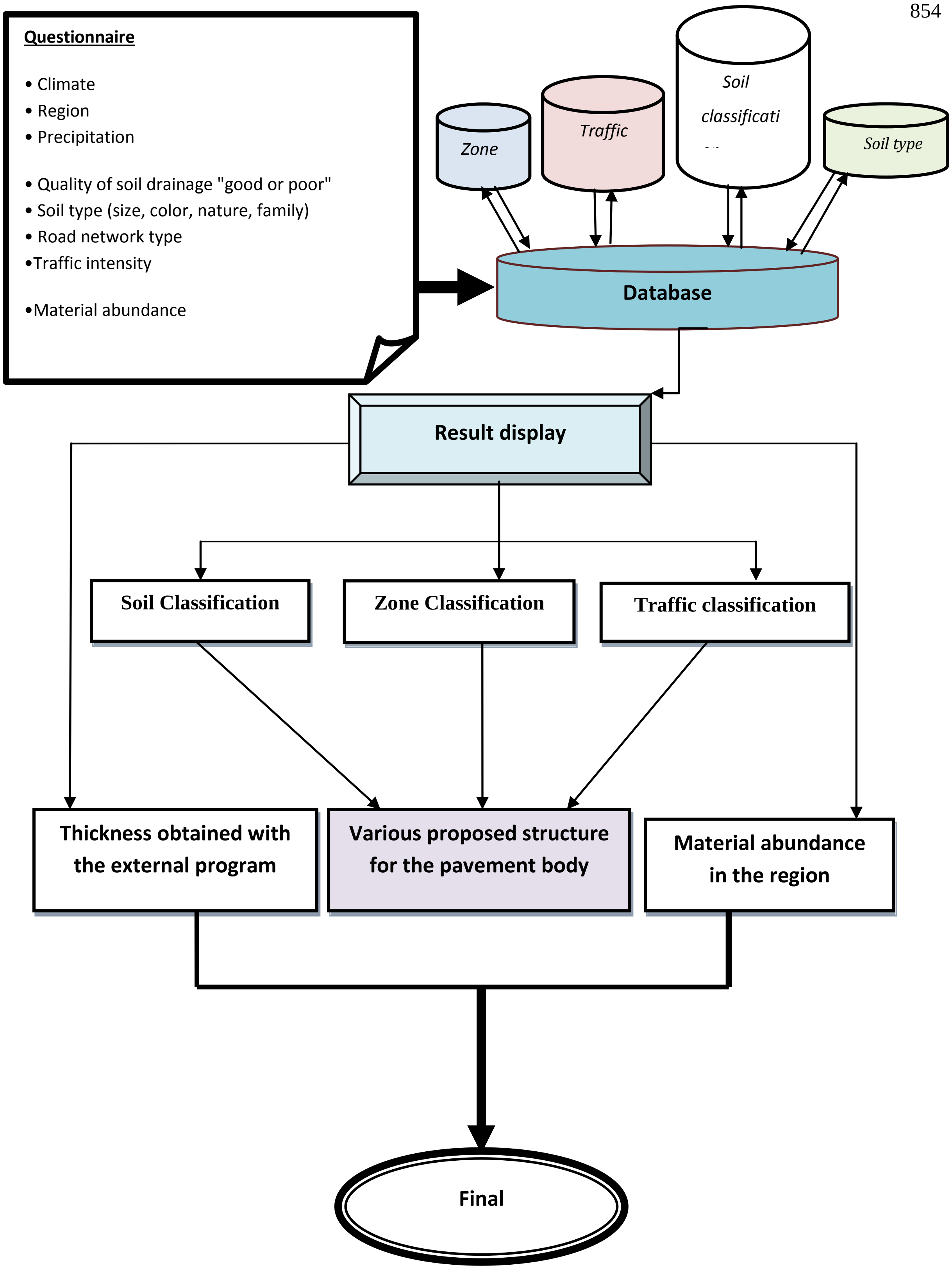
Traffic classification	Accumulated heavy vehicle traffic over 20 years
T1	$T < 7.3 \times 10^5$
T2	$7.3 \times 10^5 < T < 2 \times 10^6$
T3	$2 \times 10^6 < T < 7.3 \times 10^6$
T4	$7.3 \times 10^6 < T < 4 \times 10^7$
T5	$T > 4 \times 10^7$

The road structure layers are selected according to regionally available materials for the road project.
The final rule package retains the layer thickness variants within the intervals established for each layer of the pavement body, all while taking into account the most economic propositions with respect to the use of materials.

5. Presentation of Knowledge

The first question we must answer is to define which information is to be included into the fact database, which information to be put into the rule database and the specific information to obtain from the results, as well as its form with corresponding variables.
The user introduces the various data into the database through a question-based interface between him and the machine. The experiment is introduced into the information database through rule packages ('If' condition 'Then' conclusion). The inference engine uses these two rule databases to trigger the conclusions of the problem, then sends them back to the fact database to be displayed to the user as results during a consultation (Figure. 3). Modeling process steps:

Step 1: Introductory questionnaire
Through the questionnaire, we ask the user to enter data on the following points:
Climate region
Precipitation
Quality of soil drainage "good or poor"
Soil type (size, color, nature, family)
Type of network
Traffic intensity.


Questionnaire
• Climate
• Region
• Precipitation
• Quality of soil drainage "good or poor"
• Soil type (size, color, nature, family)
• Road network type
•Traffic intensity
•Material abundance
Zone
Traffic
Soil
classificati
Soil type
Database
Result display
Soil Classification
Zone Classification
Traffic classification
Thickness obtained with the external program
Various proposed structure for the pavement body
Material abundance in the region
Final

Step 2: Outcome 1
The tool uses its rule packages successively to determine the following parameters:
Zone
Road-soil classification
Traffic classification.

Step 3: Outcome 2
At this point the tool has at its disposal the three parameters that will allow it to determine the choice of structure that corresponds to the settings, displayed as results to the user. With the properties of the GURU expert system, we can call upon external programs, including the program written in C language used to display the already calculated pavement thickness.

Step 4: Final Results
The help tool displays: The pavement thickness,
Different structure choices proposed by the tool corresponding to the different parameters that are “Road-soil classification, predicted traffic classification and climate zone."
So according to these results, the user can make the right choice according to the materials that are in abundance in the vicinity of the project site.

Conclusions

This work involved the establishment of rules from the expert experience of professionals in the field. These rules are organized into rule packages so that the exploitation and enrichment are facilitated. At the other end of the expert system, the user will obtain proposals for body structure optimized for the pavement, either in the use of local materials or as economic solutions.
Secondly, we had to implement a tool for decision support. This tool is organized in the form of rules derived from the experiences of professionals on the subject. In our case these rules are from the new pavement catalog (version 2000).
The rules are organized into packages so that the exploitation and the enrichment are eased. Then, the programs were completed by expert prototypes, and were tested in order to ascertain their validity according to a number of cases presented in the catalog.
At our stage of this research, we have contented ourselves with establishing a non-exhaustive initial expertise which took a lot of time and effort, given the difficulty of going through all possible cases and introducing as many parameters as possible that influence the choice of pavement.
At first attempt, the validation has given us correct results, but much effort is needed to perfect the tool. This work will require a complete investigation of the tool being used, especially in the consideration of the expertise either human or documentary (dimensioning road catalogs). This work may require more research to make it operational.

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