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Original Research Article

ELABORATION OF AN EXPERT SYSTEM FOR SIZING, DESIGNING AND VERIFYING FLEXIBLE PAVEMENTS

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A b s t r a c t

The use of expert systems in the world of civil engineering, and in particular for roads, has become a necessity for the reason of the particularity, complexity, and diversity of the influencing parameters at the level of the design calculation, the latter of which represents the major source of subsequent degradation. This system consists of proposing a tool for helping the user firstly to size the body of the roadway, with several analytical methods and models (Pre-project, Boussinesq, Westgaard, and Burmister), and secondly, to offer different design possibilities (thickness and type of the material) that make up the layers. Lastly, it is to calculate the stresses and strains in order to compare them with admissible limits. The management of a knowledge base of complex natures (words, sentences, numbers, symbols, tables, calculation methods, equations, conditions, etc.) requires an adequate methodology which goes beyond the simple use of the technology but enables you to imagine the process of regrouping this mass of complex data and classifying the data, which can then be integrated into a database or spreadsheets and external programs designed with code compatible with the expert

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system generator. Our contribution relates initially to the formulation, organization, and preparation of the algorithms, and then the starting of the programs in order to conceive fully executable programs, the latter of which we can call the expert system. The validation of such a system was made as the work progressed, changes were made in the formulation of the rules, and the order and orientation of the data in the knowledge that the advantage of this type of system is the possibility of permanently reinforcing the database with human expertise in the field, or in books, especially so that we can avoid data loss due to illnesses, retirement, etc.

Keywords: expert systems, sizing, flexible pavement, database, constraints, displacements

1. INTRODUCTION

The design of pavements, as with other civil engineering structures, consists of evaluating the level of stress on the structure and comparing it with the limiting parameters of the various materials making up the structure [1]. This level of stress is evaluated by a model of pavement mechanics that researchers are trying to develop in order to make it more and more representative of physical reality, especially since the theory supposes many simplifying hypotheses. The calculation models make it possible to define the stresses and deformations that appear within a carriageway under the effect of a load and well-defined conditions. This requires the definition of parameters to describe the structure (geometry and constitutive laws) and the loading conditions (intensity of the load, contact pressure, etc.) in order to provide theoretical results corresponding to assumptions used for modeling. For other researchers in computer science, the computer is not only an investigative tool, it is itself the subject of research. This is a new axis of research named "Artificial Intelligence, one of the disciplines of computer science, and while other branches of computing are concerned mainly with increasing the speed and accuracy of computer calculations, Artificial Intelligence looks more closely at the design methods, and the possibility of machines exploiting the unique capabilities of computers to perform tasks that a century ago would have been considered a human faculty only, involving symbolic reasoning rather than just arithmetic. Knowledge modeling requires a methodology that goes beyond simply using a particular technology. In Artificial Intelligence (AI), we are mainly looking to build systems capable of solving certain tasks and the expert system belongs to this category. Its success is measured by "superficial" criteria; a system is good if it can effectively solve a certain number of tasks. To this, we add transparency and elegance criteria for the structure of the system. We want to see "why" and "how" [2].

2. RESEARCH OBJECTIVE

This study concerns the development of an expert design system for dimensioning and designing of layers and verification of stresses and deformations in flexible pavements (ES-DDV). This system will have the role of facing all the problems encountered by beginners in road engineering in the construction of flexible pavements. In addition, a number of sub-objectives, including the various uses of ES-DDV, are addressed in this study. ES-DDV is used as a tool to make quick decisions and share expertise, as an educational tool for engineers or civil engineering students, and as an archive of primary and human knowledge for all types of engineers in the Field of study. The design of such an expert system will help engineers, entrepreneurs, and students in making fast and reliable decisions and in preserving the experience of experts in this practical area. Generally, all the decisions are related to the situation of the particular problem and that decision must be taken in limited time [3]. It will also ensure conservation of the transfer of knowledge gained in the studies and of the problems encountered, and the solutions proposed. Such a policy and the design of such a system will help to avoid huge problems in the field of road design in the future, where time, cost, and the methods adopted are of paramount importance.

3. EXPERT SYSTEMS

Expert systems had their heyday in the 1980s when it was assumed too quickly that they could develop massively. In practice, the development of this kind of application is very hard because, when one exceeds the hundred-hour rule, it becomes difficult to understand how they thought the system could develop to such a large extent. All the expert systems operational today came into being after the year ‘76 [4] and touch a variety of fields of application (medicine, chemistry, physics, geology, botany, mathematics, law, and building). In many areas, there is also an emergency support system for decisions made in the event of a breakdown [5].
The application of expert systems in the field of civil engineering seems adequate and can facilitate and assist in the design and control of various works. A set of expert systems have been designed to meet the technical needs in the field of public works, or laws and methods that do not follow any predefined algorithm, but rather follow more human experience and understanding as well as prediction with some Uncertainty coefficient of unexpected soil behavior. The current study discusses the development of the Expert System for the Control of Construction Problems in Flexible Sizing and Design of Flexible Pavements (ES-DDV). Various expert systems have been developed (Table 1).

Table 1. The history of expert systems during the last years

Name	Expert system
EXPEAR	Expert system for Pavement Evaluation And Rehabilitation
SCEPTRE	Surface Condition Expert system for Pavement Treatment and Rehabilitation
ERASME	French acronym for highway maintenance assisted by a multi-expert system
PAVEMENT EXPERT	Expert system to evaluate concrete pavements
PARES	Pavement Rehabilitation Expert System
Unavailable	Pavement design expert system
Unavailable	Expert system for pavement materials selection and evaluation
PAVEDKB PDS	Expert system for pavement materials selection and evaluation
PMAS	Pavement Management Advisory System
PAVER and Micro PAVER	Expert systems to identify the demand and priority in pavement maintenance
PMDSS	Pavement Management and Decision Support System
Unavailable	Image-based expert approach to distress detection on CRC pavement
PAVE	Expert system to identify failure reasons in flexible pavement
EXSPAV	Expert System program established for use in flexible pavement and overlay design
F3PS	Fuzzy Pavement Performance Prediction System
PERMIT-EXPERT	Knowledge-based system for evaluation of superboard permit application
RC-MSS	Road Construction Material Selection System
ES-DMFP	Expert System for Design Module in Flexible Pavement
ES-HGDesign	Expert System for Highway Geometric Design

Here, implicit knowledge is required, whereas an apprentice engineer is not qualified to perform this type of task; however, the number of experts is insufficient to cover the number of projects in this field, as well as the decreasing number of experts, has become a serious concern. Therefore, a system that can archive the experiences of engineers over the years and provide that knowledge before and during an existing project is important, while failure to leverage past knowledge results in the recurrence of prior errors [6]. The documentation, classification, and computerization of problems, their probable causes, solutions, and protective procedures can help control and prevent the recurrence of these mistakes.

3.1. Architecture of the expert system

The expert system consists of three modules [7], see figure (1)

1. The knowledge base brings together knowledge specific to a given subject area in a form that can be used by a computer. A database that is only formalized in a declarative way, i.e. its role is to welcome the specific knowledge of the field of application, either directly provided by the experts or accumulated by the system itself during the experiments [8]. It is split into two parts:
   - the basis of fact (B.F) is constituted by the set of facts defining the problem posed to the system on the one hand, and by the set of facts deduced from the system as the progression of the profusion.
   - the knowledge base itself, which groups together all the knowledge provided by the expert to the system on a specific area [9].
2. The inference engine is the central part of the expert system, it is in the form of a relatively general program that exploits the knowledge of the database by considering it as data (and therefore liable to be changed).
3. Interfaces: In addition to these two basic components, there are various essential elements (interfaces) that gave the expert system generators:

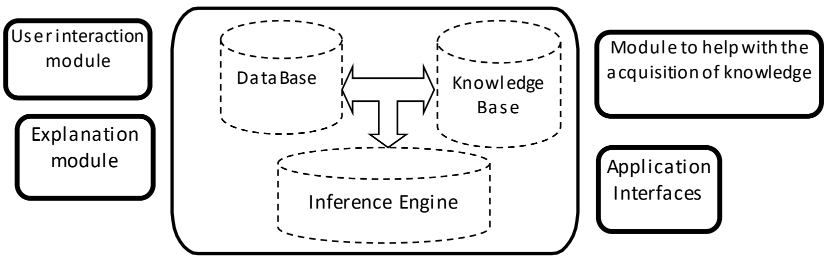


Fig.1. Expert System Representation and its interfaces

3.2. Expert system operation

1. Forward chaining: forward chaining reasoning thoroughly 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, the expert system 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 a goal during the research.
3. Mixed chaining: is the combination of the two types: forward and backward. The use of an expertise is called a consultation. It executes the commands of the INITIALIZATION clause, then analyzes in an order that it itself determines the RULES that can give a value to the goal, and finally it executes the Closing clause, whether the goal is found or not.

3.3. Implementation of the expert system

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 to each type of problem. A generalized inference engine can reason with any rule database [10]. Thus, the task of creating an expert system is reduced to the building of 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**.** We preferred for this stage to be based on two references; Mechanical methods and models for pavement design and the Catalog of dimensioning of new pavements, version (NOVEMBER 2003) because it constitutes a document of more recent Algerian character which gathers the results of specific studies of the behavior of the Algerian materials, which allowed the national dimensioning of the structures. It comes in the form of dimensioning sheets in which the structures are already pre-calculated. These pre-calculated structures call upon the knowledge of a certain number of accompanying documents (standards, technical guides, recommendations). These technical datasheets summarize for each technique, with reference to national and foreign documents, the main specifications as well as the recommendations concerning the manufacture, implementation, and control [11,12].

3.4. The formulation of the expertise

This system consists of developing flexible pavement dimensioning methods through the programming of the theoretical models exposed in the book, and the basis of all road software, and inserting the content of the technical sheets drawn from the Algerian catalog of new pavements as well as offering suggestions and choices of body composition for the road. This proposal is of course based on the mechanical characteristics of the foundation soil (bearing capacity, composition, sensitivity to water, frost, thaw, etc.), types of loads, and the availability of materials around the project site [13]. The implementation of such a system will provide significant computing time savings to engineers and owners to avoid making costly bad decisions.

3.4.1. Principle of technical sheets

The technical files are a set of files grouping together the models of structures already calculated and presented according to the road network, the value of the traffic, the zone, and the classification of the ground. The package allows the introduction of the geotechnical characteristics of the foundation-soil according to climatic zones. We have selected three major areas characterizing Algeria: Littoral zone, Highland zone, and Saharan zone. A second rule package allows the introduction of the geotechnical characteristics of the foundation-soil according to climatic zones (Table 2).

Table 2. Climatic zones [12]

Climatic zones	Annual precip. **(mm/year)**	Climate	Region
I	> 600	Very humid	North
II	350-600	Humid	North, Highland zone
III	100-350	Semi-arid	Highland zone
IV	< 100	Arid	South

Following that, and according to the road classification by climatic zones (different from geographic zones) of which there are four (04), they are defined as a function of hydrometric as well as drainage quality (Table 3) and the CBR index (%) of maximal density modified PROCTOR (4-day immersion) applicable to flexible pavements (Table 4). Where we adopted this classification of soils for Algerian roads (Table 5), 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.

Table 3. Load carrying capacity classification of soil [12]

Categories	CBR index (%)
S0	> 40
S1	25 to 40
S2	10 to 25
S3	5 to10
S4	< 5

Table 4. classification of soils for Algerian road [12]

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 or 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 or poorly calibrated	S2	S3	S2	S3	S1	S1
Alluvium	Fine silty clayey	S2	S3	S2	S3	S1	S1
	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
Tufa	Salted bottomland	S3	S4	S2	S3	S1	S2
	Encrustation	S1	S1	S1	S1	-	-
Marl	Granular horizon	S1	S2	S1	S2	-	-
	Structure	S3	S4	S2	S3	S1	S2
Silt	Organic soil	S4	S4	-	-		-

Table 5. Traffic classification [12]

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	$T > 4 \times 10^7$

3.4.2. Flexible pavement dimensioning methods

The role of pavements is to distribute the pressure exerted by the tire to bring it to a level compatible with that which 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 supposed to achieve lower cost while still giving optimal conditions of comfort and security. To do so, there are two very different approaches to dimensioning the pavement, one is empirical and the other theoretical. The application of a repeated rolling load on the foundation soil causes bending strains in the structure layers. The latter leads to compressive stresses perpendicular to the load, and tensile stresses at the base layers of the foundation. The application of a repeated bearing load on the foundation soil causes bending deformations of the structural layers. Given the multitude of models mentioned in the research, we chose a single model to present in this study, knowing that the prototype includes the different models from the simplest to a single layer (Boussinesq model), the two-layer model (Westgaard and Hogg), and the n-layer model (Burmister model). The principle of the Boussinesq model is that the load applied to the road is represented by q_0, a pressure (of the order of 2 to 7 bars) generally exerted by the tire, which generally cannot be supported by natural soil classification [20].

The load on the ground is represented by a pressure q0 on a circle of radius a, the ground support is a semi-infinite solid, supposed as a homogeneous linear isotropic elastic Young's modulus E2 and Poisson's ratio ν2. The soil cannot withstand vertical stress (σz) without deforming, below the admissible pressure q0. The problem in all models is to find this depth H in which the vertical pressure σz does not exceed the admissible σz of the soil, then, according to the equivalence coefficients of the road materials, we can choose the appropriate component of the structure of the pavement body and in the same way, calculate at each depth z to know the strains and the radial and tangential stresses classification [21,22].

Boussinesq could solve this problem and identify the constraints, hence the vertical stress z is shown in figure 2.

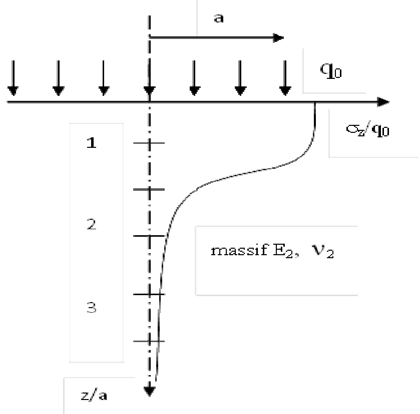


Fig. 2. Pressure diffusion in massive Boussinesq

Equations (3,1), (3,2), (3, 3), and (3,4), respectively, represent the calculation of the vertical stress, the radial stress, the shear stress, and the displacement.

$$\sigma_Z = q\left[1 - \frac{Z^3}{\left(a^2 + Z^2\right)^{\frac{3}{2}}}\right] \tag{3.1}$$

$$\sigma_r = \frac{q}{2}\left[\left(1 + 2V_2\right) - \frac{2Z\left(1 + V_2\right)}{\left(a^2 + Z^2\right)^{\frac{1}{2}}} + \frac{Z^3}{\left(a^2 + Z^2\right)^{\frac{3}{2}}}\right] \tag{3.2}$$

$$\tau_{\max} = \frac{\sigma_Z - \sigma_r}{2}$$
$$= q\left[\frac{\left(1 - 2V_2\right)}{4} + \frac{Z\left(1 + V_2\right)}{2\left(a^2 + Z^2\right)^{\frac{1}{2}}} - \frac{3Z^3}{4\left(a^2 + Z^2\right)^{\frac{3}{2}}}\right] \tag{3.3}$$

$$W = \frac{q}{E_2}\left[\begin{array}{l} 2\left(1 - V_2^2\right)\left(a^2 + Z^2\right)^{\frac{1}{2}} - \dfrac{\left(1 + V_2\right)^2}{\left(a^2 + Z^2\right)^{\frac{1}{2}}} + \\ Z\left(V_2 + 2V_2^2 - 1\right) \end{array}\right] \tag{3.4}$$

4. METHODOLOGY

The user has the different data entered in the database through a questionnaire between them and the machine. Experience is introduced into the knowledge base using rule packets (If condition Then conclusion). The inference engine uses these two rule bases to trigger the conclusions of the problem, it sends them to the fact base to display to the user as a result, during a consult. Our methodology guided us to divide our work into four parts, demonstrated in figure 3.

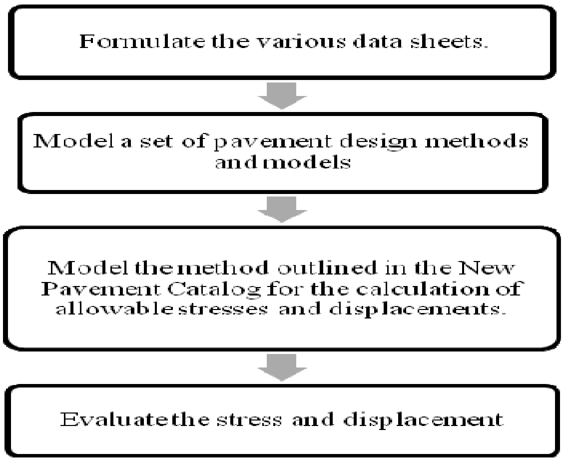


Fig.3. Phases of reasoning

The first question we must answer is to define which information is to be included in the fact database, which information is 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 them and the machine. The experiment is introduced into the information database through rule packages ('If' condition 'Then' conclusion) [14] and [15]. 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 4 summarizes the general organization of the methodology adopted, and the organization of the system.

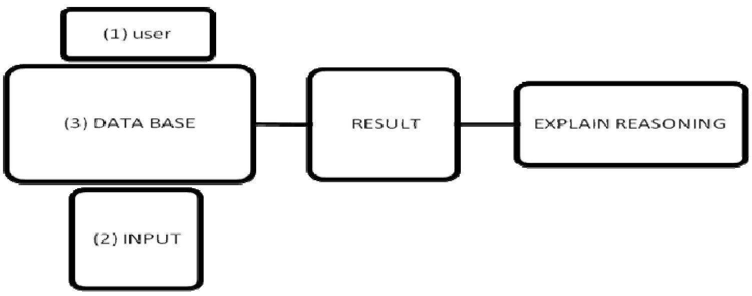


Fig. 4. System Mode of operation

- **Step 1** an initialization operation was carried out to be able to follow the various steps through a questionnaire introduced in the form of an initialization menu. 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, and Traffic intensity - figure 5.

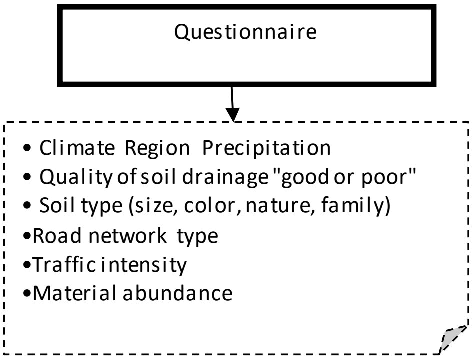


Fig. 5. Questionnaire with user

- **Step 2** The tool uses its rule packages successively to determine the following parameters: Zone, Road-soil classification, and traffic.

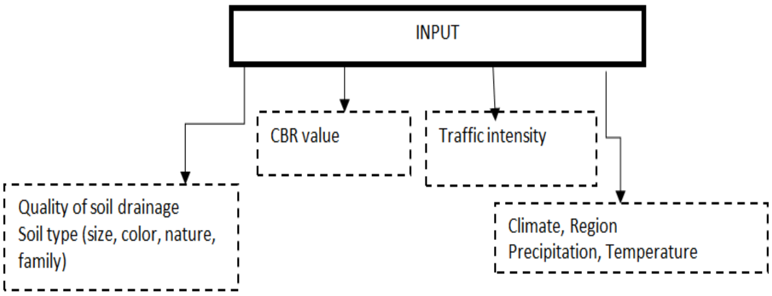


Fig. 6. The input parameters

the main data entered is in the form of a dialogue between the user and the machine through questions in the form of character input numbers and words. The window below summarizes this conversation.

Input Region **Car** With "The Footwear Is Implanted In The Region Of"
Input Preci **Num** With "The Precipitation In This Area Is Of: mm/year"
Input Climate Car With "The Climate Of This Region Is:"
Input Traffic Num With "The Traffic Provided For This Road Is: hw/day/sens.
Input I Num With "Cbr Index From: "
Input Family Car With "What Is The Nature Of The Soil: "
Input Rate Num With "What Is The Value Of The Growth Rate"

Input Soil Car With "What Is The Family Of This Type Of Soil"
Input Drainage Car With "The Quality Of Soil Drainage Is:"

- Step 3 Database

The knowledge base consists of a set of ‘IF’.. ‘THEN’ ... describing ways known to the expert to analyze the information from the database. The ‘IF’ part of the rule is generally named a ‘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 [16].

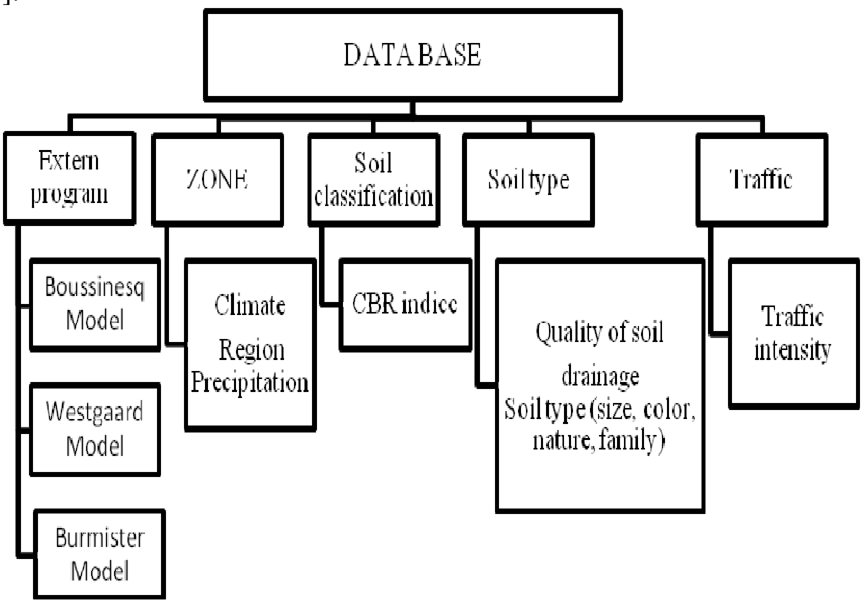


Fig.7. Structure of the Database

Figure 8 shows the rules management menu (creation, deletion, copy, search, or rename) and Table 6 shows an example of each rule packet relating respectively to the area, soil classification, traffic, and the pavement structure component. The database contains 250 integrated rules in the form of packets relating to the various parameters influencing the design of the roadways.

Table 6. Rules Examples

DESIGN STRUCTUR	
STR1	IF: (TRAF > 3000 and TRAF < 6000) AND (I > 10 AND I < 25) AND (CLASSEMENT = S2) AND (ZONE = 1 OR ZONE = 2) THEN: STRUCTUR = "STR1"
STR2	IF: (TRAFFIC > 3000 AND TRAFFIC < 6000) and (I > 10 AND I <= 25) AND (CLASSEMENT = "S2") and (ZONE = 1) OR (ZONE = 2) THEN: STRUCTUR = "STR2" output " structur = 8BB+12GB+13GB OU 10BB+21GL+21GL",STR2 NEEDS: TRAF ZONE CLASS
STR3	IF (TRAF > 3000 AND TRAF < 6000) AND (I > 40) AND (CLASSEMENT = "S0") AND (ZONE = 1)
STR4	IF: (TRAF > 3000 AND TRAF < 6000) AND (I > 40) AND (CLASSEMENT = "S0") AND (ZONE = 1) THEN: STRUCTUR = "STR3" OUTPUT "str3" NEEDS: TRAFFIC CLASS
ZONES	
Z1	IF: (PRECI > 600) AND (CLIMAT = "THUMIDE") AND (REGION = "NORD") THEN: OUTPUT " ZONE = 1",Z1 Z1 = 1 ZONE = 1
TRAFFIC CLASSEMENT	
T1	IF: (TRAF> 150 AND TRAF <300) THEN: TRAFFIC = T3 AND NETWORK = RP2 AND \ OUTPUT "TRAFFIC = T3 AND ROAD NETWORK IS CLASS IN RP2", TRAFFIC
SOIL CLASSEMENT	
S11	IF: (SOL = "GRAVE" AND FAMILLE = "PRGRAD") AND (ZONE = 1 \ OR ZONE = 2) AND (DRAINAGE = GOOD) THEN: CLASS = S1 output "class = s1", CLASSCLASS = S1

5. SYSTEM VALIDATION, ANALYSIS, AND DISCUSSION

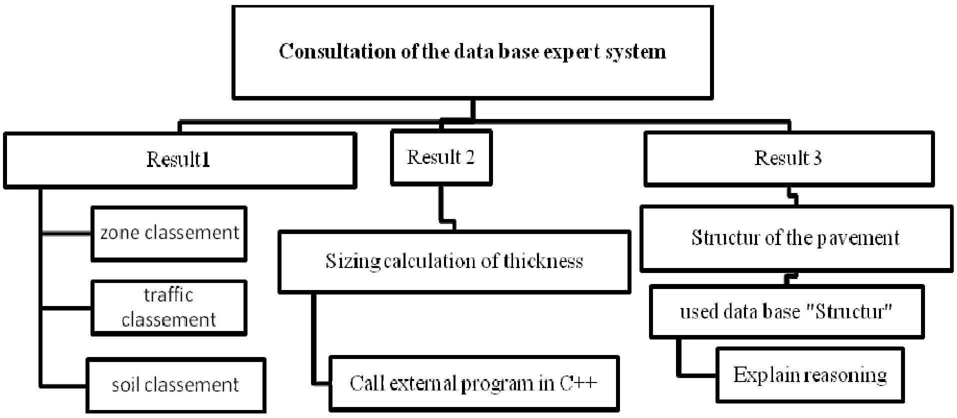


Fig. 8. Consultation of database

The expert system generator is mainly done through a questionnaire that is automatically displayed as soon as the goal is specified, then the inputs are entered as shown on the example.

5.1 The questionnaire below shows an example of the answers

The road is located in the region of: **North**
The precipitation in this region is: **800.00 mm/year**
The climate for this region is: **Very humid**
The planned traffic: **4000** hw/day/sens
The CBR index: **20**
What is the nature of the soil: **silty fine**
What is the family of this type of soil: **sand**
What is the drainage quality: **Good**

The help tool displays (figure 9) the pavement thickness and the 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, according to the introduction of a database specific to the integration of information relating to materials available in the region.

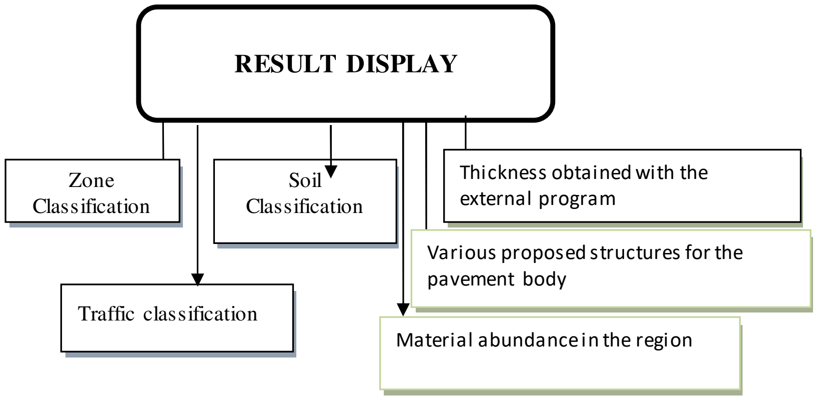
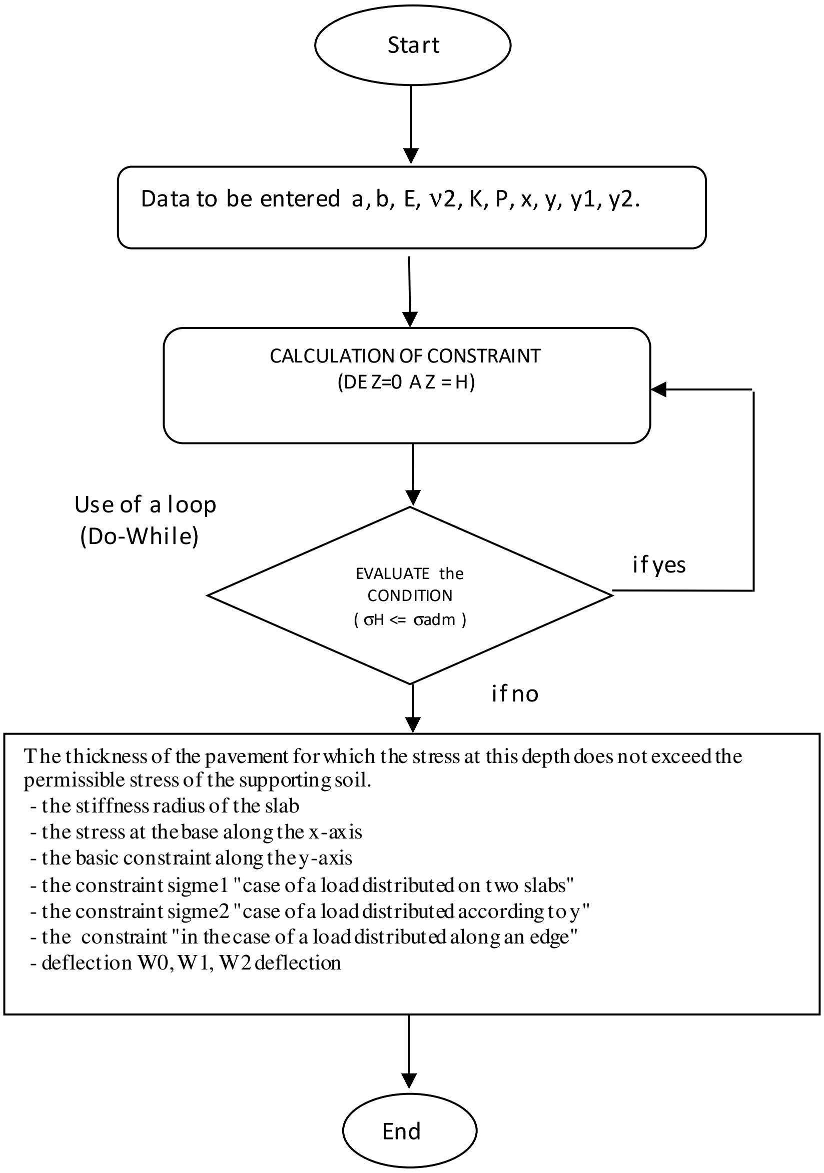


Fig. 9. Procedure for consulting the expert system

5.2. Result 2

A proposal to run a set of external programs for the calculation of pavement thicknesses, constraints, and relative displacements. The call of the external programs is done directly, one chooses the menu option "MANAGEMENT" then "Run outside program". For that purpose, it is enough to describe the name and the destination of the file. Calculation of the thickness of the pavement and the corresponding stresses are "stresses and deformations" through different design methods, each external program is conceived through an analysis of the calculation method and thinking about how to treat the idea, to make the algorithm, then to write the program, and lastly to check the execution and the results obtained. Execution of external programs in C ++, conceived for several models, from a simple one that treats the pavement as a single layer of soil, to the most complicated one which treats the body as a set of layers of different superimposed materials. The system consultation goes through the consultation of datasheets, being the steps to follow, and the modeling consists in the programming of some mechanical models with a suitable programming language, in order to find the thickness, the constraints, and the displacements. The C++ language represents the best choice of programming language, being placed among the most professional software at the top of lists of other programs like Pascal, the Basic, and for several reasons most flexible, and the program of choice for professional programmers, containing few words, just a handful of phrases called keywords [17].

The principle of this programming is to seek the maximum depth of the body of the roadway for which the stress at this depth reaches the maximum value but provided that it is less than or equal to the allowable stress of the ground support. For each calculation of thickness, the calculation of the different displacements and constraints is done.


Start
Data to be entered a, b, E, ν2, K, P, x, y, y1, y2.
CALCULATION OF CONSTRAINT
(DE Z=0 A Z = H)
Use of a loop
(Do-While)
EVALUATE the
CONDITION
(σH <= σadm)
if yes
if no
The thickness of the pavement for which the stress at this depth does not exceed the permissible stress of the supporting soil.
- the stiffness radius of the slab
- the stress at the base along the x-axis
- the basic constraint along the y-axis
- the constraint sigme1 "case of a load distributed on two slabs"
- the constraint sigme2 "case of a load distributed according to y"
- the constraint "in the case of a load distributed along an edge"
- deflection W0, W1, W2 deflection
End

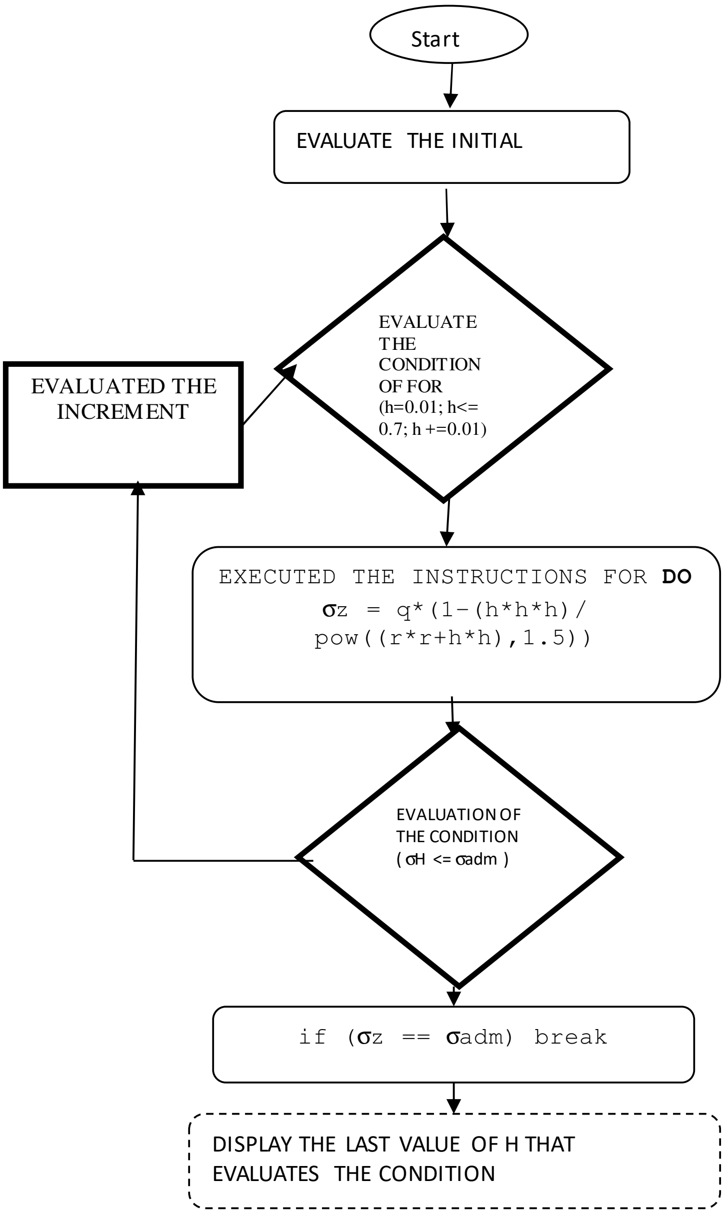


Fig.10. Boussinesq method programming algorithm
a- General algorithm. b- Loop algorithm (for do-while)

Step 2 Consult the STRUCTUR database, this database is designed by feeding all the rules relating to traffic, the zone, the classification of the soil, the

formulation of datasheets, etc. it includes a set of rules in the form of *if Condition then Premise*.
The following results are displayed where we have one or more types of structures

----

The region belongs to the climatic zone:1
The road classification of the soil is: S2
the Traffic classification is:
The proposals of the body structure of the roadway is:
Str3 = = 8cm asphaltic concrete + 11cm bituminous gravel + 11cm bituminous gravel
(8AC+11BG+11BG)
Or 10cm asphaltic concrete +21cm bituminous gravel +21cm bituminous gravel
(10AC+21BG+21BG)
Or 16cm Portland cement concrete +16cm Portland cement concrete
(16PCC+16PCC)

5.3. Explain reasoning

This module explains the path of the rules as well as the coefficient of certainty by rule, by goal, or by line of reasoning.
Verification and validation are the most important and most difficult tasks involved in intelligent system development. Verification can be performed through testing activities to verify that the correct system is being built. In effective testing, each test should aim to detect a fault. Each stage and all components of the system should be tested [18]. Testing is performed periodically during the system development process to guarantee that each activity in the system is performing the intended functions. ES-DDV is evaluated by a number of test procedures, as explained in the following sections. Verification and validation are essential in the development of expert systems. Table 7 Comparing the results between catalog and expert system.

Table 7. Explanation of the reasoning of the result obtained by the expert system

Tool	Description	Explanation
by goal	How #Goal Structur (From Pavement.Rsc) Str3 += Str3	The system displays the name of the database goal.
by rule	How #Goal Structur (From Pavement.Rsc) Str3 += Str3	The system displays the rule drawn
by Line of reasoning	WHY Rule Str3 (From Pavement.Rsc) Traffic += T7 Classement += S2 Zone += 1 Structur += Str 3	The system displays the name of the rule drawn with its content

Table 8. Validating the results

PARAMETER	DATA	CATALOG	EXPERT SYSTEM	Similar y/n
Zone	region of: **North** The precipitation in this region is: **800.00 mm/year** climate: **Very humid**	Zone 1	Zone1	Yes
Traffic	traffic: **4000** hw/day/sens	hgti 6	hgti 6	Yes
Class soil	CBR index: **20** nature of the soil: **silty fine** family of soil: **sand** drainage quality: **Good**	S1	S1	Yes

Table 9. Similarity of the results obtained by the expert system and the catalog

DATA	CATALOG	EXPERT SYSTEM	Similar y/n
Structure	Plug N° 1 8 Bituminous concrete + 11cm bituminous gravel + 11cm bituminous gravel Plug N°6 10cm asphaltic concrete +21cm serious dairy +21 cm bituminous gravel Plug N°7 16cm Portland cement concrete +16cm Portland Cement Concrete	Str3 = 8cm asphaltic concrete + 11cm bituminous gravel + 11cm bituminous gravel 8BC+11SB+11SB **Or** 10cm asphaltic concrete +21cm bituminous gravel +21cm bituminous gravel 10SB+21SD+21SD Or 16cm Portland cement concrete +16cm Portland Cement Concrete 16PCC+16PCC	Yes

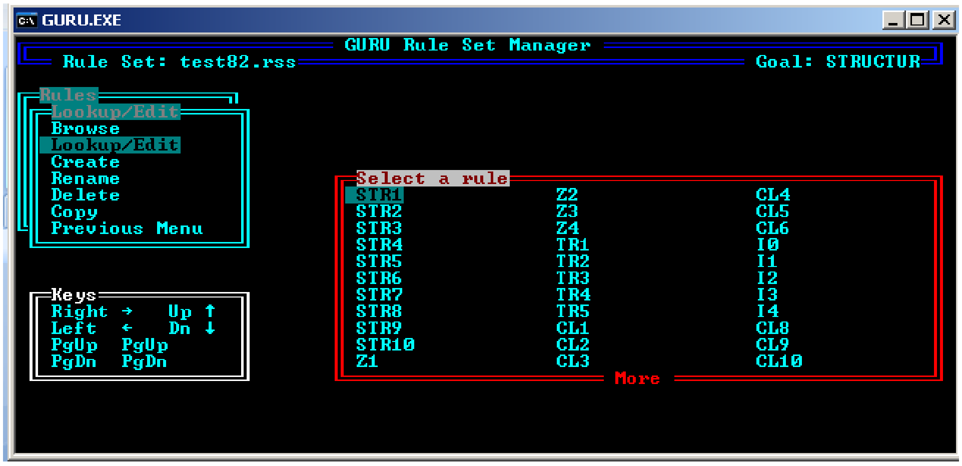


Fig.11. Menu of rules

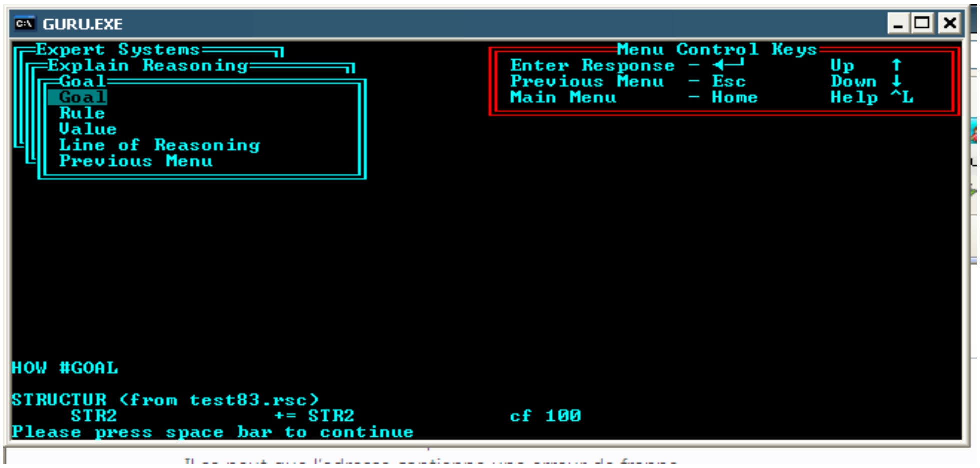


Fig.12. Menu explain reasoning by goal

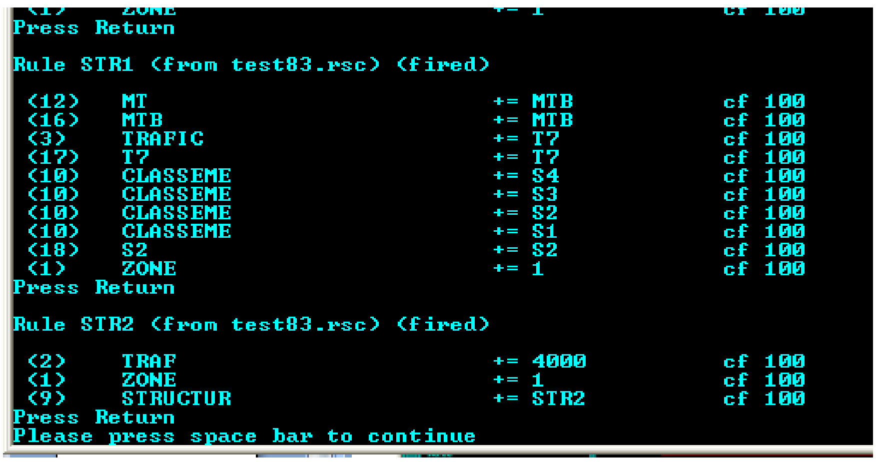


Fig. 13. Display of rules drawn Page

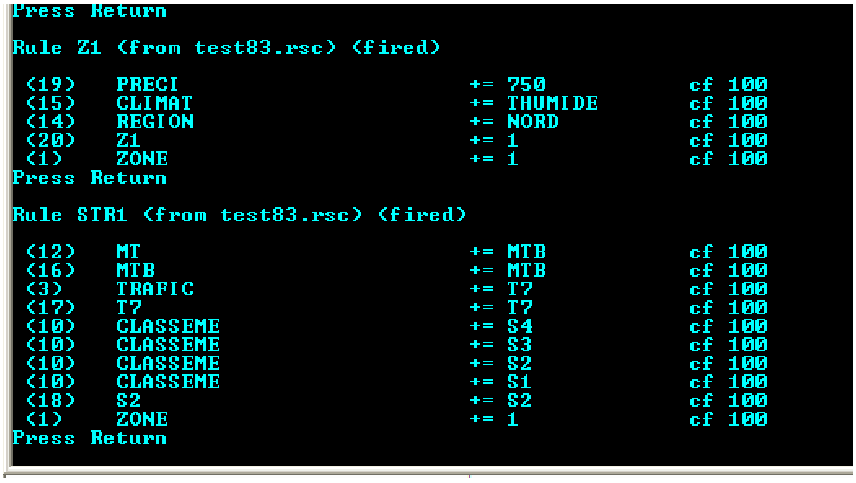


Fig. 14 Display of rules drawn

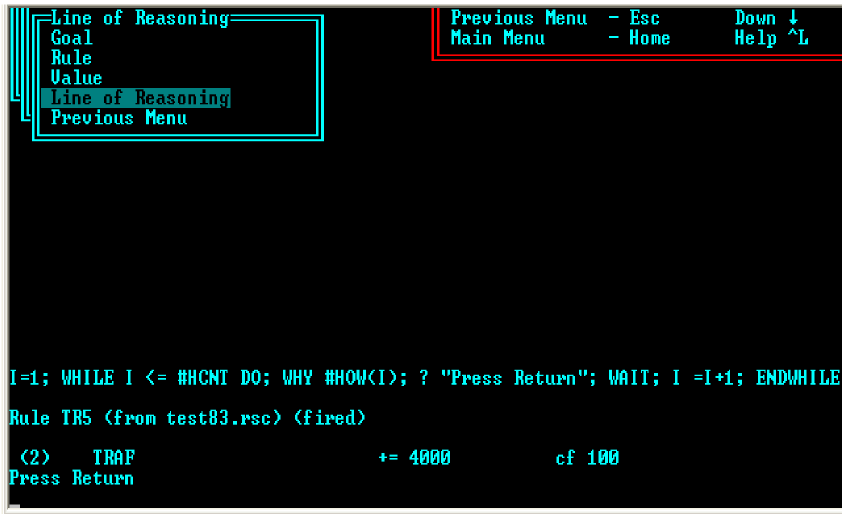


Fig. 15 Display of line of reasoning

Verification is performed effectively testing the functions of system components and detecting faults to ensure correct system construction. The system is periodically tested during the build phase to verify the functionality of its Activities. The ES-DDV has been tested effectively, and the last results are described in the subsections. The verification of the effectiveness of the expert system is the consultation of the database.

6. CONCLUSION

In general, pavement design rules are based on geotechnical knowledge of the soil and the deformability characteristics of materials determined by laboratory tests as well as observations on the behavior of structures and on mathematical methods: rational approaches using an adapted mathematical model, and finally, confrontation between technological knowledge and theoretical results [19].

In this article, we have walked through a set of expert systems edited and designed for roads, the majority of which deal with rehabilitation problems, traffic management, and degradation diagnostics [20,21]. The implementation of such a tool is mainly part of the development and implementation of a new generation of decision support tools in the field of civil engineering. The current ES-DDV system is defined as a set of independent and communicating modules. It is broken down into three basic phases: the construction of the databases, the consultation of the databases, and the explanation of the reasoning. It is intended for dimensioning, designing, and checking the stability of flexible pavements.

The implementation of this system is such that the user only has to answer simple questions and the system takes care of providing the various data relating to the area, the classification of the ground, the classification of the traffic, on the one hand, and on the other hand, to offer a variety of sizing and verification methods in order to estimate the equivalent thickness of the pavement, the component of the body of the pavement, and the verification of stability.

The difficulty we have encountered is the operation of regrouping and organizing the enormous quantity of knowledge and data, and of approaching human reasoning, which does not follow a well-defined algorithm and which allows a succession of different levels of knowledge heterogeneous in nature, with flexibility and speed. The validation of the results comprised two stages; firstly the execution of the programs relating to the dimensioning methods and then that the proposals drawn from the consultation of the database are identical to that described in the catalog.

We can conclude that the system has given us favorable results and has helped to reduce the consultation time of various documents. The important characteristic is that the expert system generator offers the flexibility to build, modify, and consult different databases. This use of expert systems in engineering, and more particularly in the field of civil engineering, has become a global priority.

Notation

l = stiffness radius of the slab;
a and b = half-axes of the ellipse in (m);
E = Young's modulus of the slab in (mpa);
q_0 = load applied to the ground;
K = the soil reaction module in (mpa / m);
x and y = coordinates of point M located under or near the load, in (m);
ν = fish coefficient of the slab;
y1 = ordinate of point M located on the axis of symmetry perpendicular to the edge, in the case of long loading of an edge or a joint, in (m);
y2 = ordinate of point M located on the axis of symmetry perpendicular to the edge, in the case of load distributed over two slabs, in (m);
H = Depth of the pavement;
z = Depth of the ground (m);
σz = Vertical stress (mpa);
traff = Traffic;
Str 3 = proposal of the pavement body structure;
hgti = Heavy goods traffic;
hw/day/sens = heavy weight per day and per direction.

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