Transactions on Information and Communications Technologies vol 1, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

Concept and practice of expert systems in civil engineering

E. Bernardi & P.R.C. Sardinha

Civil Construction Division Computer Section, São Paulo State Institute of Technological Research, Brazil

ABSTRACT

Firstly, this paper gives an overview of general concepts of expert systems: their parts, when expert system building is justified and appropriate, and phases and tools necessary to develop them.

Secondly, expert systems are associated with some basic characteristics of civil engineering problems, such as incompleteness and inaccuracy of data, multidisciplinary approaches and the need of complementary qualitative analysis. Examples of expert systems in many civil engineering branches such as structural, geotechnical and environmental engineering are cited.

Finally, a practical experience of building an expert system demonstration prototype in flexible pavement maintenance domain is reported.

INTRODUCTION

Although in the beginning of the 60's some researchers were working to reproduce human reasoning to solve generic problems, only in the beginning of the 80's expert systems, that had worldwide repercussions due to their ability to solve problems in determined knowledge areas, were developed. Some of those expert systems were the MYCIN for diagnosis of infectious diseases, the PROSPECTOR for geological data interpretation and the MOLGEN for planning experiments in molecular genetics.

Transactions on Information and Communications Technologies vol 1, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

With such positive repercussion, expert systems were considered a great solution and a lot of money was invested in them. But, in a short period of time people noticed that, although expert systems are capable of solving problems that one couldn't solve with traditional programming techniques, they had some limitations. Their development was time consuming and they didn't solve all types of problems.

After that initial euphoria, some partially unsuccessful experiences led to a certain discredit. But, in the following years, some criteria and shells for helping expert systems building were developed, and at the end of the 80's a more realistic view of them emerged. Nowadays, there are new, well succeeded, experiences in many knowledge domains and expert systems begin to occupy their strict role.

CONCEPT

In this topic basic concepts of an expert system and its development are treated.

What expert systems are

Artificial Intelligence is the part of computer science that studies themes related to human intelligence simulation in a computer. It has branches such as natural language, robotics, perception (vision and speech), neural networks and expert systems.

Resulting from researches about simulation and reproduction of human reasoning to solve problems, expert systems are computer programs that, quickly and efficiently, can solve problems as a human expert does. They are interactive programs and can process experience, judgement and intuition.

Differently from ordinary programs, expert systems represent knowledge symbolically using characters involving complexity, uncertainty and ambiguousness (and not only certainty and determinism so common when working with algorithms).

To hold this knowledge, expert systems apply many strategies and use heuristic intensively (that is, the use of procedures that, although they can't be proved, lead to the solution of the problem quickly).

Parts of an expert system

An expert system has five main parts: the knowledge acquisition module, knowledge base, inference engine, explanation mechanism and user interface.

Transactions on Information and Communications Technologies vol 1, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

The knowledge acquisition module is the system part that interfaces with the knowledge engineer or with the human expert, offering resources to add and modify the knowledge represented in the knowledge base.

In the knowledge base the procedures, strategies and reasoning that a human expert uses to solve a certain problem are represented. This knowledge is symbolically represented and organized using facts (data) and rules (or other representation) that can be associated with certainty factors.

The inference engine is a structure that has an algorithm capable of using the knowledge base effectively. It has an interpreter that decides how to apply the rules to infer new knowledge, and a scheduler that decides the order in which the rules should be applied. There are two ways of chaining the rules that are being analyzed: the forward-chaining and the backward-chaining.

The explanation mechanism stores information about how expert systems reach their conclusions, that is, the decisions that are being made by the system during the solution process of a certain problem.

The user interface is the component through which the user can communicate with the system. It supplies data and information or obtains results, conclusions and explanations about how and why the system reached a certain solution.

When to build an expert system

It is very difficult to describe in general terms the characteristics that make a problem appropriate for an expert system development. Waterman [1] talks about some aspects that can help one to decide:

– Expert system development is possible when it can be validated, this meaning that there are human experts studying the problem, and they agree about their solving methods, the choice and preciseness of the solution.

– An expert system is justified when human experts are expensive or scarce or there is a great demand for them. Or when the human expert decision making must take place in a hostile environment. Or the knowledge is getting lost, for example, because of high rotativity of personnel in a company.

– It is appropriate when it involves heuristic knowledge and the problem can be solved naturally by manipulating symbols and their structures. When the problem can be solved with mathematical models one must use algorithmic methods. Moreover, the problem must be complex or difficult enough to justify the cost and effort of an expert system development.

Phases of expert system development

The development of an expert system involves the following phases: knowledge acquisition, knowledge formalization, implementation and tests.

Knowledge acquisition involves direct and interactive contact between the human expert and the knowledge engineer. The knowledge engineer takes the expert knowledge, conceptualizes and formalizes it. In this phase one can be faced with the main difficulty in expert systems building: expert knowledge acquisition and formalization. Faced with realistic problems to be solved, the human expert has a tendency to show his reasoning and conclusions in a generic way, very far from that necessary for a computer analysis. He combines pieces of his basic knowledge so quickly, that it is difficult for him to describe this process in detail.

Knowledge formalization involves expressing concepts and relations in a formal way. There are many techniques that use mechanisms associated to the characteristics of human intelligence to represent the knowledge. They copy the way humans represent their knowledge. These techniques are called formal way or knowledge representation methods and the most used are: rules, semantic nets and frames. Rules are based on structures like IF (premise) THEN (conclusion) or IF (condition) THEN (action) and they are a natural way to describe dynamic processes; they work very well for problems driven by the data, where deviations are common. Semantic nets and frames provide a natural way to structure a taxonomy, that is, problems that involve relations/hierarchy.

The implementation phase turns the formalized knowledge into a computer program. In this phase one must use an expert system tool for development, and its choice will depend on the type of problem, knowledge formalization and tool features.

Finally, the test phase involves the evaluation, revision and validation of the expert system facing real problems.

Expert system tools for development

Tools for building expert systems are basically software resources that can be divided into three categories: programming languages, system-building aids and knowledge engineering languages.

Programming languages used to develop expert systems are generally the languages that have flexibility for the knowledge base implementation, inference engine construction, and which allow for the development of many interface resources. Some examples are problem-oriented languages such as FORTRAN and PASCAL, symbol-manipulation languages such as LISP and PROLOG, and object-oriented languages as SMALLTALK.

System-building aids are projected mainly to help knowledge acquisition and design. Through the definition of the problem, which involves all the possible decisions, its attributes and values, the system will ask the user for examples describing the conditions that led him to this decision. Some of these systems are the EXPERT-EASE, RULE-MASTER and SEEK (e.g. Waterman [1]).

Knowledge engineering languages are a complete set of resources used to build expert systems, combining language power with a sophisticated interface and support environment. They are commonly called shells. Most of them are based on rules and have their own inference engine. They are useful for inexperienced development groups, because they offer facilities for editing, debugging, executing and interfacing (such as explanation facilities). Some of these shells are general-purpose such as OPS5, EMYCIN, M.1, KEE, ROSIE, VP-EXPERT, FUZZY-EXPERT, GURU, NEXPERT, TEARS, G2 and PATER (the last one was developed in Brazil) (e.g. IPT [2]). Some others are more oriented for diagnostic problems such as PERSONAL CONSULTANT and SeRIS.

Support services for using these shells are, in general, not available in Brazil, and this fact has brought many difficulties during expert system developments and sometimes has postponed them.

ENGINEERING APPLICATIONS

Although engineering is an exact science, it is also a knowledge area that involves a lot of intuition and experience. This is naturally clear when we think about the number of experts and consultants necessary to make diagnoses and reach solutions for the majority of problems we encounter.

On the other hand, engineering usually manipulates a great volume of incomplete and/or inaccurate data to see the feasible alternatives for the problem. In these cases qualitative analysis is frequently more important than the quantitative ones.

Additionally, engineering nowadays uses more and more multidisciplinary knowledge to treat problems, such as making an

Transactions on Information and Communications Technologies vol 1, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

environment impact analyses of a great civil work, or planning the traffic control of a big city, or designing and analyzing a medical prosthesis performance (e.g. Bernardi [3]). These characteristics are extremely favorable for using expert systems.

Very successful in medicine and financial areas, expert systems took a long time to be disseminated in engineering, but today there are many prototypes that are leaving universities and research centers to become products used by companies.

Civil engineering applications

All characteristics described above can be found in civil engineering.

In environmental civil engineering, one of the most important characteristics is the involvement of multidisciplinary areas (chemistry, biology, fluid mechanics, mathematics, statistics, economics, law, etc.). Expert systems in this area usually deal with hazardous waste management, water quality protection and water resources. Some examples (e.g. Maher [4]) are the FRES for deciding emergency responses in chemical spills; the RPI and GEOTOX for aiding the evaluation of hazardous waste sites; the QUAL2E Advisor for suggesting appropriate input values for QUAL2E that predicts water quality impacts of pollutant discharges on rivers and streams; and the Flood Advisor for modeling estimate design floods for civil engineering projects.

In structural engineering expert systems have aided design, analysis, inspection and maintenance, and code checking. There is also a great potential application for diagnosis and interpretation problems. Most of the expert systems developed in this area involve interaction with conventional calculus and analysis programs, and the expert system is an aid to conceive models and to understand structural behavior. Some examples (e.g. Maher [4]) are: HI-RISE for preliminary design of high-rise buildings; BDES for helping the analysis, modeling and decision about the better bridge superstructure design; and VibDiag for vibration diagnosis. Other examples are INDEX for industrial building design (e.g. Adeli [5]); RAISE-1 for diagnosis of safety and integrity of structural systems (e.g. Adeli [5]); and an Expert System for the diagnosis of building defects (developed in Singapore, e.g. Mathur [6]).

Geotechnical engineering is an area marked by the manipulation of incomplete and/or inaccurate data, that depend on the sensitivity and skill of an expert who is able to extrapolate and infer good results. That is why this area is very good for building and using expert systems. There are also many applications involving the interpretation of parameters of a heuristic nature

Transactions on Information and Communications Technologies vol 1, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

in general, and others that interact with conventional programs. Some examples are CESSOL for analysis of geotechnical investigation problems (e.g. Bigot [7]) and EXSEL for diagnosis and treatment of dam seepage problems (e.g. Adeli [5]). Other examples (e.g. Maher [4]) are CONE for soil classification and inference of shear stresses using cone penetration test data and RETWALL for the choice of alternative designs for retaining walls.

Transportation engineering involves planning, design, control and operation, management and maintenance activities; and in all of them computers are essential tools. Though, many problems can't be solved by the usage of numerical algorithms because they involve skill and judgement of human experts and they encompass social, political and human behavior elements. Expert systems have been a very useful alternative in these cases. An example of this is planning and design of traffic networks. Some examples of expert systems (e.g. Maher [4]) are PARADIGM that integrates some expert systems to present strategies for regional pavement maintenance; CHINA for the design of highway noise barriers; and HERCULES to generate traffic control plans to avoid congesting situations. Other examples are Pavement Expert for evaluating concrete pavement performance (e.g. Topping [8]) and Management of Low Volume Flexible Pavement that recommends pavement rehabilitation and maintenance strategies (e.g. Aougab [9]).

Applications for planning and management of civil construction works can also be found in various references (e.g. Maher [4]).

PRACTICE

A practical experience in building a demonstration prototype of an expert system in engineering, performed at the Civil Construction Division of IPT, will be reported.

The choice of a domain

There are many application areas (domains) for expert systems development in engineering. For this first experience pavement maintenance was chosen. This domain has two basic characteristics: it has a great short term potential interest for the community and the Civil Construction Division of IPT has a lot of accumulated experience in this domain (e.g. IPT [2]).

The dimension of the road network of the biggest states in Brazil, its importance as a means of communication and transportation of goods among regions, and pavement age, since many roads were built many years ago, show the increasing need of a constant, quick and efficient maintenance.

Transactions on Information and Communications Technologies vol 1, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

In many countries such as Chile (e.g. C. [10]), the U.S.A. (e.g. Aougab [9]), Canada and England (e.g. Topping [8]) expert system development is emerging to help engineers who work in public offices responsible for road and street maintenance.

Expert systems, gathering experience from pavement experts who have developed successful maintenance strategies, can help less experienced engineers to adopt adequate maintenance and recuperation systems even with limited or incomplete data.

It was made an evaluation that an expert system for pavement maintenance should be appropriate and useful in Brazil. It should also be of extreme interest and usefulness in many city offices and public organizations directly connected with the problem as the Road Engineering Department of the São Paulo State. Therefore, the Computer Section and Pavement Group of Civil Construction Division of IPT gathered their efforts to build a demonstration prototype of an expert system for urban flexible pavement maintenance.

Knowledge acquisition

The knowledge acquisition phase was done through bibliographic technical material (such as technical bulletins, reports, photos) and periodic meetings with two pavement experts.

Both activities were conducted by two engineering researchers that act as knowledge engineers. They are graduated in civil engineering and computers.

Initial work was done to define the limits of the chosen domain more precisely. Initially a broad attack of the problem was discussed. Through the use of diagrams and flowcharts more strict limits were redefined. The initial approach had involved problem identification, analysis, tests and suggestions of preventive and corrective attitudes, and later the domain was restricted to the identification of the problem and its causes.

The first phase of knowledge acquisition was characterized by terminological, conceptual and mainly common sense problems. These problems were surpassed by the adoption of concepts and common definitions, resulted from the discussion between the experts and their review of the information obtained in the bibliographic material.

The conclusion that some defects called "concentrated settlement" and "depression" could be treated as a unique defect is an example. Another example is the concepts of normal and excessive traffic, the first one defined as traffic for which the road was projected and the last as traffic above the projected.

Acquisition, that was done initially without a methodology (only with a gathering of knowledge in the area), was done in a more organized form after the start of the knowledge formalization. Using a pavement defect enumeration, knowledge engineers and experts simulate many situations and phenomena related to the defect, obtaining for each simulation the probable cause of the defect.

For example, the knowledge engineer asked the expert to imagine a pavement with "block cracking". Then, the engineer added more information, such as normal traffic, pavement is three years old and so on, until the expert reached the defect causes or concluded that the information had no consistency. The process went on until the complete acquisition of the problem knowledge was reached.

Knowledge formalization

The knowledge formalization phase started immediately after the limit definition of the domain in the knowledge acquisition phase. Since the beginning it was natural and immediate that the representation would be done using rules (as defined in preceding topics).

Actually, these two phases were developed together, and the methodology used for knowledge formalization generated a parallel methodology for knowledge acquisition. Initially a defect was chosen and a group of situations (attributes) more common and immediate were added. Using the assemblage defect plus situations the cause (conclusion) was reached.

Then, other values for the situations (maintaining the same defect) were added and new causes for these new combinations were obtained. An example of formalization is:

BLOCK CRACKING +
NORMAL TRAFFIC +
PAVEMENT AGE LESS THAN 5 YEARS +
NO DEFORMATION =>
BAD QUALITY OF WEARING COURSE (VERY STIFF)

Tool choice

Considering the inexperience of the group in expert system development and the lack of financial resources, it was decided to acquire a national and simple tool called PATER 2.0 (e.g. TECSIS [11]).

PATER 2.0 is a shell for expert system development based on rules type "IF ... THEN ... ELSE ...", easily used due to its friendly user interface, in spite of its limited resources. It allows for creation, execution and debugging expert systems in a completely integrated environment. It works with concepts such as attributes, values and variables and has an inference engine that uses backward-chaining. It was a good tool for building a demonstration prototype with the characteristics described before.

Knowledge base implementation

This phase started with the definition of the attributes, their values and variables. Then the rules were constructed.

The situations/conditions as being attributes and variables were defined with the knowledge formalization. The attributes are situations/conditions that have their values well-defined by intervals. The variables are also situations/conditions but their values must be treated in more flexible intervals in the rules.

An example of attribute is "TRAFFIC" that can assume the values "NORMAL" and "EXCESSIVE". An example of variable is "PAVEMENT AGE" that, depending on the rule, can have different intervals of value, that is, "PAVEMENT AGE < 5 YEARS" and "2 YEARS < PAVEMENT AGE < 10 YEARS".

Due to the problem domain and the methodology adopted in knowledge acquisition and formalization, the first step in knowledge base construction was the creation of the attribute "DEFECT" with its values (names of the defects) with its descriptions. Then, new attributes, values and variables were incorporated in the base for the construction of the rules.

An example of an implemented rule is:

IF
Defect = Block_Cracking
and
Traffic = Normal
and
Pavement_Age < 5
and
Deformation = No
THEN
Problem = Bad quality of wearing course (very stiff)

Status report

The knowledge acquisition and formalization phases are concluded. With the conclusion of the implementation phase it was possible to consult the base, creating a feed-back process that led to a refinement of the acquisition and formalization already done. It is interesting to observe that with this feed-back process all phases were executed at the same time.

Now, with the end of knowledge base construction some tests with other experts and users should be carried out to validate and, eventually, refine the knowledge base.

After this an extension of the domain of this demonstration prototype will be discussed. In this extension the goal system will be able to give suggestions about preventive and corrective attitudes to be adopted for the analyzed pavement.

CONCLUSIONS

Nowadays expert systems are a consolidated technique and many engineering problems have characteristics that can be treated by this technique. The tendency is to increase the number of products available in the market.

In the case of the demonstration prototype described in this paper, experience has shown one more time that the "bottleneck" in an expert system building resides in the knowledge acquisition. But, the results were hopeful. It is intended to build a final product probably using more advanced tools for the development and including some graphic resources for user interfaces in the near future.

ACKNOWLEDGEMENTS

The authors thank IPT, especially the colleagues of the Pavement Group, and FAPESP for the opportunity of divulging this paper.

REFERENCES

1. Waterman, D.A. *A Guide to Expert Systems.* Addison-Wesley, U.S.A., 1987.

2. IPT - Instituto de Pesquisas Tecnológicas do Estado de São Paulo. *Sistemas Especialistas em Engenharia Civil.* Relatório nº 28.932. São Paulo, 1991.

3. Bernardi, E., Sardinha, P.R.C. 'Sistemas Especialistas: Conceito e Prática', in XIII CILAMCE, Vol. 2, pp. 421-431, *Proceedings of the XIII Congresso Ibero Latino Americano sobre Métodos Computacionais para Engenharia*, Porto Alegre, Brazil, 1992.

4. Maher, M.L. (Ed.). *EXPERT SYSTEMS for Civil Engineers: Technology and Application.* ASCE, New York, 1987.

5. Adeli, H. (Ed.). *Microcomputer Knowledge-Based Expert Systems in Civil Engineering.* ASCE, New York, 1988.

6. Mathur, K.S., Leng, A.A. 'Efficacy of expert system technology for the diagnosis of building defects - a case study'. *Building Research and Information*, Vol. 20, n. 5, pp. 307-312, London, 1992.

7. Bigot, G., Marchal, J., Moreau, M.C. 'CESSOL - Systeme expert pour les reconnaissances de sol dans le domaine du bâtiment'. *Bulletin de Liaison des Laboratoires des Ponts et Chaussées*, n. 154, pp. 110-112, Paris, 1988.

8. Topping, B.H.V. (Ed.). *THE APPLICATION OF ARTIFICIAL INTELLIGENCE TECHNIQUES TO CIVIL AND STRUCTURAL ENGINEERING*, Pro. AI CIVIL-COMP, Civil-Comp, Edinburgh, 1987.

9. Aougab, H., Schwartz, C.W., Wentworth, J. 'Expert System for Management of Low Volume Flexible Pavements', pp. 759-768, *Proceedings of the Fifth Conference on Computing In Civil Engineering: Microcomputers to Supercomputers* (Ed. Will, K.M.), Alexandria, Va., 1988. ASCE, New York, 1988.

10. C., Carlos Videla, G., G. Echeverria, L., Marcelo Puig et al. 'GIMP: UN SISTEMA DE INFORMACION COMPUTADORIZADO PARA LA GESTION INTEGRAL DE PAVIMENTOS ASFALTICOS', in XI CILAMCE, pp. 623-642, *Proceedings of the XI Congresso Ibero Latino Americano sobre Métodos Computacionais para Engenharia*, Rio de Janeiro, Brazil, 1990.

11. TECSIS. *Manual do Usuário do PATER.* Rio de Janeiro, Brazil, 1990.