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Autor: Liu, Xila

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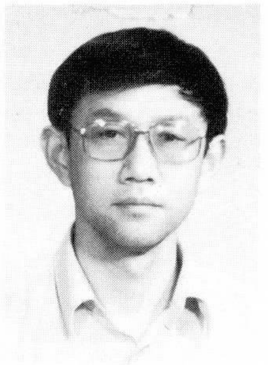
Decision Making System in Civil Engineering in China

Système d'aide à la décision en génie civil en Chine

Expertensysteme zur Entscheidungsfindung im chinesischen Bauwesen

Xila LIU
Professor
Tsinghua University,
Beijing, China



Xila Liu, born 1940, received his Ph. D. at Purdue University, West Lafayette, USA. He is a member of Board of Directors of China Civil Engineering Society, and also the deputy director of Research Institute of Structure Engineering at Tsinghua University.

SUMMARY
In the present paper, a significant Project «Intelligent Decision Support Systems in Civil Engineering», which is supported by the National Natural Science Foundation of China, is introduced. Several examples, such as some new reasoning methods and successful expert systems, are described briefly. Special attention is paid to the discussion on the task selection, the system applicability, and the system framework.

RESUME
Dans cet article, un important projet intitulé «Les systèmes du support de la décision intelligente dans les travaux publics» subventionné par le Fonds National chinois des Sciences Naturelles est présenté. Quelques exemples tels que nouvelles méthodes de raisonnement et systèmes experts sont décrits succinctement. On y relève spécialement la discussion du choix des tâches, aptitude du système à l'emploi et la structure du système.

ZUSAMMENFASSUNG
Ein bedeutendes Projekt «Das System der intelligenten Entscheidung für Bauingenieure», unterstützt von der Staatlichen Stiftung der Naturwissenschaften in China, wird in diser Abhandlung vorgestellt. Einige Beispiele, wie neue Schlussfolgerungsmethoden und erfolgreiche Expert-Systeme, sind kurz dargestellt. Besondere Beachtung findet die Diskussion der Aufgabenauswahl, der Systemanwendbarkeit und des Strukturaufbans.

1. INTRODUCTION

Computer, as an powerful calculational tool, has been developed for over 40 years. It seems that, in every 4 to 7 years, as a cycle, the calculation speed of computers increases to 10 times, and the volume and cost decrease to 10 times. This general trend is going on. There is no any industrial product which can compete with computer development. In this case, the civil engineering, as an very aged engineering domain, will certainly be changed by the great influence.

One of the significant changes in civil engineering is that the engineering theories are softenning, while the engineering experiences are hardening. In other words, as shown in Fig.1a, people are accustomed to input certain data and to pick up some certain output data through calculation procedure. Since a large amount of uncertainties of information or knowledge, such as ignorance, fuzziness, and randomness, exist, engineers have to input uncertain data and to receive some answers or conclusions by experience or inference, which is shown as Fig.1b. It is so-called "Theory softenning".On the other hand, a great deal of experience and knowledge of civil engineers in practice can be acquired, coded and stored in computer, which is called "Experience hardenning".

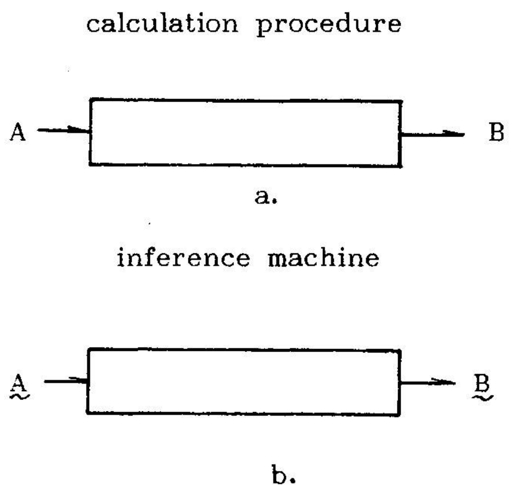


Fig.1

It is well-know that there are two major approaches in decision-making systems of civil engineering. One is to build a comprehensive mathematical model for the project. However, in most cases, this approach is not feasible because the available knowledge of the system is not sufficient, even though the computer develops quickly. Another approach is based or the experience of civil engineers. It is very often to solve an engineering problem without calculation or by engineer's intuition.

After the development of artificial intelligence, especially the development of knowledge Engineering, it is possible to develop some methodologies which imitate the actions of human experts in decision-making procedure. The intelligent decision-making system in civil engineering means that the two major approaches, which are mentioned above, are combined organically. This decision making system does not mean that the decision could be made entirely automatically. Human being must be involved during decision-making process. Strictly speaking, the intelligent decision making system in this paper is a knowledge-based decision support system, i.e., a generalized expert system.

In the first part of this paper, the development of intelligent decision making systems in civil engineering in China is reviewed. And them, several examples, such as some new reasoning method and successful expert system, are described. Some suggestion, which include very important philosophic thinking in knowledge engineering, is introduced in last part of this paper.

2. BRIEF HISTORY

Although the research works of knowledge-based systems or expert systems have been started in China over 20 years, the artificial intelligence technique has been used in civil engineering just for a couple of years. In the United states, the first knowledge-based expert system, SACON, was developed in 1978, which is later than Feigenbaum's DENDRAL, the first expert system in the world, for almost 10 years. Similarly, in China, the earliest knowledge-based systems in civil engineering were developed in 1985 to 1986, which are also later than those developed in other domains, such as the medical diagnostic domain. The reasons can be summed up as follows:

(1) during planning, design, construction, and maintenance, too many factor are in volved;
(2) very strong interactions exist among these factors;
(3) a great deal of uncertain information or knowledge have to be considered;
(4) in most cases, the civil engineering projects are tailor-made and often kept in service very long. It is difficult to do a statistical survey.

It should be noted that, since 1985, the artificial intelligence technique has been conspicuous in civil domain in China. A great many universities and research institutes are involved in the development of various intelligent decision making systems or expert systems. The enthusiasm is getting higher and higher. The increase rate is shown in Fig.2. According to the situation of

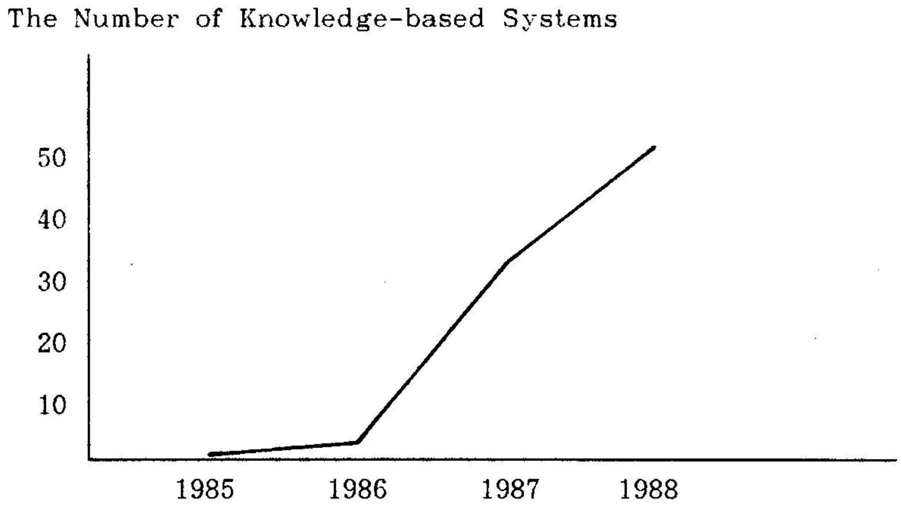


Fig.2

Chinese reconstruction, the incitement factors can be found as following points.

(1) There are tremendous number of civil engineering projects in China. Since the constraint of financial resources, the scientific decision-making is needed badly. It is well known that the decision-making process in civil

engineering is semi-structural or ill-structural. Many uncertainties have to be considered. Any decision mistakes may damage the society and may last very long.

(2) After the cultural revolution, almost one generation of experienced engineers has been last. China is really short of senior engineers in civil engineering. Many old engineers are going to be retired. In order to save their expertise, the knowledge acquisition and coding by knowledge engineers are really needed.

(3) Following the widespread of knowledge engineering and the marketing of various soft-wares or shells, it is possible build more systems. Especially, Chinese scholars have very strong background of the uncertain inference and mathematics.

(4) The National Natural Science Foundation of China can organize a very large group to work on such projects and gives sufficient financial support. Many professors and senior engineers joint together and work on the same project with low payment.

For example, there are more than 500 million square meters' industrial building existing in China, which contain almost 50 billion yuan facilities. Most of them are undergoing, to some extent, the deteriorates or damages. Some of them have been close to their intended usage lives. Their functions, or even safety, may be not satisfactory any more. According to the financial resources of China, the construction policy is that the maintenance and modification of the function of existing buildings are primary, the construction of new buildings is secondary. At first, it is urgently needed to assess the damage of existing buildings in order to make appropriate strengthening or maintenance plan. as mentioned previously, however, since the complexity and the uncertainty of existing buildings and the shortage of senior engineers in China, only a few experts are really qualified to make such assessments. In this background, knowledge-based expert system in the domain of damage assessment of existing buildings have made great progress in China.

Since 1985, the research works on following systems have begun : (1) A man-machine system on Seismic Damage Analysis developed in the Institute of Engineering Mechanics (IEM) of the State Seismological Bureau. (2) A expert system for Earthquake Intencity Evaluation (EIE) developed in Chinese Academy of Building Research. (3) Expert systems of Damage Assessment of Existing Reinforced Concrete Industrial Buildings (RAISE-1, ARCS-1) [2] [3] developed in Tsinghua University, Sichuan University, and the Sichuan Institute of building Research. In 1987, the expert system of Building Project Bidding Estimation (BPBE-1) [4] was built in Tsinghua University and has been market. Also in 1987, a big research project, "Intelligent Decision Support Systems in Civil Engineering", was organized by the National Natural Science Foundation of China (NSFC). The project is supported by NSFC and 7 Ministries or Bureaus, 25 universities and research institutes and almost 220 researchers, which include almost 90 professors or senior engineers, are involved. Ten aspects are included, such as

(1) Intelligent Decision Support Systems of Urban Planning;
(2) Seismic Risk Analysis and Protection;
(3) Railway Construction;
(4) Highway and Water Transportation Engineering Design;
(5) Environment Evaluation of Construction Projects;
(6) Preliminary Design of High-rise Buildings;
(7) Construction Management and Cost Prediction;

(8) Damage Assessment of Existing Buildings;
(9) Intelligent CAD and Simulation;
(10) Treatment of Uncertain Information in Civil Engineering;

In these 10 aspects, there are 31 subprojects included. It is expected that, after 5 years, a group of more complete knowledge-bases will be built in various domains of civil engineering. This is the first task in the significant project. and a number of applicable systems will be developed. Meanwhile, some new inference theories will be available. Besides, a large number of young knowledge engineers will be nurtured and educated in this project. In 1988, it is found that, among 31 subprojects, in most of them, a demonstration prototypes has already been developed. Some systems are going marketing. In this case, it should be mentioned that it really takes time to build an applicable, robust system. The strict practice check is entirely necessary.

3. UNCERTAINTIES IN CIVIL ENGINEERING

3.1 The Sources of the Uncertainties

Uncertainties of information or knowledge exist in three forms: ignorance, fuzziness, and randomness.

From information point of view, there are three sources of uncertainties. The first is the insufficiency of the primary information, which causes the ignorance. Sometimes, the information contradiction also belongs to the ignorance. The second is the simplification of problems. For example, the cracks in an existing structure may present themselves in any position and their shapes may relate to various causes. However, for convenience, experts often divide the cracks into finite types, such as flexual cracks, shear cracks, nodal cracks, ect.. Fuzziness arises when experts decide which type a certain crack belongs to. The third is the randomness, such as loads and structural resistance.

From knowledge point of view, however, the uncertainties have two sources. One is the fuzziness because of the complexity of the problem. For example, the reliability of an existing structure can be inferred from the safety, the function integrity, and the durability of the structure. Since the relations among them are rather complex, experts are unable to understand the relations completely. In other words, to conduct the inference, experts use fuzzy knowledge. The other source is the randomness due to the unreliability of the knowledge. For example, rule of "if the strength safety factor is enough, then the structure satisfies safety" is tenable in most conditions. However, if the rule is applied to damage assessment of a certain structure, it is not always correct.

3.2 Classification of Reasoning Methods

There are two kinds of events in the real world: two-valued events and continuous-valued events. The events such as the freeze of water are two-valued events because the truth value of the proposition of "the water freezes" can only be 1 or 0. The events such as the damage of a structure are continuous-valued events because the truth value, or the assessment value of the proposition of " the structure is damaged" may take any value in [0,1]. Problems involving only two-valued events are called two-valued problems, while problems involving continuous-valued events are called continuous- valued problems.

Primary information and inference knowledge may be certain or uncertain. Correspondingly, certainty and uncertainty reasoning methods will be developed.

At present, reasoning methods are divided into reasoning methods of two-valued problems and of continuous-valued problems, each of them being further divided into certain and uncertain reasoning methods (Table 1).

Table 1 Classification of Reasoning Methods

type of problem	reasoning characteristic	representation of uncertainty	reasoning method	example
two-valued	certain		classical syllogism	
	uncertain	certainty factors	certainty factor method	MYCIN
		probabilities	probability method	PROSPECTOR
continuous-valued	certain		decision-making table or combination function method	ARCS_1 [3]
			membership function method	RAISE_1 [2]
	uncertain	fuzzy measure	possibility method	
			belief function method	RAISE_2 [13]
		fuzzy subsets	plausible reasoning	
		truth restriction	truth function modification	

It seems that most of available reasoning methods used in mentioned systems are certain or uncertain reasoning methods of two-valued problems. Some attempts were made to establish uncertain reasoning methods of continuous-valued problems [5]. Many people in China prefer to introduce the fuzzy set concept. It should be noted that, up to now, the concept of degree of member ship, the cornerstone of fuzzy set theory, is not yet explicitly clear [6]. What is it's meaning in nature and how to determine it are crucial issues for applications. The fuzzy set theory does not satisfy the complementary law. What kind of influence it may induce during the inference process should be strictly checked.

3.3 The Combination Function Method

The following is a brief introduction of a new approach to model the inference process of expects, which is developed by Prof. Z.F.li, Sichuan University in 1987 [7].

In the practice of modelling the expert inference, a lot of knowledge possessed by human experts can be mathematically represented in the form of function as

$$Z = F(x_1, x_2, \ldots, x_n) \tag{1}$$

How to acquire and represent such a function F is an important issue in building knowledge-based systems. It is interesting to know whether or not the function F can be decomposed as follows

$$F(x_1, x_2, \ldots, x_n) = x_1 * x_2 * \ldots * x_n \tag{2}$$

where * is a binary operation satisfying some conditions, such as associativity, commutativity and so on. If Eq.(2) holds, the complex problem of acquiring and representing the function F of n variables could be reduced to a much simpler one, in which only the binary operations are needed.

On the other side, it is well known that the fuzzy set theory provides a natural frame for uncertainty management. Finding appropriate aggregative operations for fuzzy sets is an important issue not only in theory but also on its applications. Suppose that $A_1, A_2, \ldots, A_n$ are fuzzy subsets of a space X, A is an aggregate of $A_1, A_2, \ldots, A_n$, and x is a point of X. Mathematically, the membership of x in A, i.e. the z, is a function (may be multi-valued) of memberships $x_1, x_2, \ldots, x_n$ of x in $A_1, A_2, \ldots, A_n$, respectively. This function is called combination function. Up to now, almost all investigations on fuzzy set theoretic operations only deal with the binary operations. Thus, a problem arose natually: can all combination functions be represented as Eq.(2)?

Based on the measurement theory, Prof. Li proved that [7].

Let F: $[0,1]^n \to [0,1], n \geq 3$, be a function. Then F can be represented as

$$F(x_1, x_2, \ldots, x_n) = f^{-1}\left(\sum_{i=1}^{n} f_i(x_i)\right) \tag{3}$$

where f and f_i are continuous strictly increasing functions, satisfying $f_i(0) = 0$, and iff F is continuous, satisfying some conditions, such as the variable-independence condition with respect to (0,0,...,0).

In order to show how powerful the Eq.(3) is, the following example is given. Assume n=6, and each X_i and z has 7 admissible values. thus, if Eq.(1) is expressed by a decision-making table, then $7^6 = 117649$ groups of data are needed and there are 7 numbers in each group. However, if Eq.(3) is used, even in the tabular form, only (6+1)*7=49 groups of data are needed, there are only 2 numbers in each group. the number of data is reduction to 1/8403. When n increases, the reduction is more efficient. This method has been successfully used in an expert system ARCS_1 for damage assessment of reinforced concrete mill buildings [3].

4. SOME MARKETETABLE KNOWLEDGE-BASED SYSTEMS

4.1 BPBE_1: Building Project Bidding Estimation (Tsinghua University) [4]

BPBE_1 is a knowledge-based cost estimator for bidding on a new building project. It provides construction cost estimation by accessing a knowledge-base of construction expectise and cost databases. The four major modules of BPBE_1 are: (1) Chinese interpretation system; (2) inference machine; (3) a coat database of typical project with decision-making tables; and (4) knowledge-base of cost estimating expertise and bidding policy with a dynamic database. The cost database was derived from C-BASICA and C-DBAS III, and the system can be performed on Great Wall 0520 or IBM-PC.

The methodology can be briefly described as follows. For different type of buildings, a different vector of characteristic cost factors can be determined by expectise. According to the number of characteristic cost factors a multidimensional cost space is built. The loaction of many typical projects can be found in the cost space, which depend on the vector coordinates, i.e., the values of the characteristic cost factors. During making a bid for a new project, the vector coordinates should be determined first and the location of the new project in the cost space can be found. Then, the "distances" between the new project and the original typical projects can be calculated. The cost estimation of the new project can be obtained by the weighted integration. Of course, the weights and scores of related factors depend on the "distances". Obviously, this methodology is very similar to the bidder's thinking. In practice, comparing with the results from the bidding experts, the average accuracy is better than 97%.

4.2 RACODE_1: Reliability Assessment of Reinforced Concrete Mill Buildings (Tsinghua University) [8]

RACODE_1 is a knowledge-based decision support system based on "Specifications of Reliability Assessment of Metallurgical Industry Structures" [9]. A large number of experts and senior engineers spent almost 3 years for editing this specifications. Although the assessment details of each part in the metallurgical industrial structures are given respectively, it is found that, in practice, the synthetical decision is hardly made. In RACODE_1, the probability theory of fuzzy event and the cut set theory are used. According to some decision rules from experts, the final decision, how to treat the assessed existing building, can be clearly given.

The system is written in GCLISP and can be implemented on IBM-XT. The primary information can be input by a man_machine dialog system in chinese. The final output includes the damage level and the maintenance suggestions. After assessing 600000M^2industry buildings, the comparison between the system output and the expect assessment are very satisfying.

5. SOME COMMENTS

5.1 Task Selection

It is proved that careful selection of the task to be encapsulated in an expect system is essential for the success of the system development project. Several criteria for choosing projects and tasks have been enumerated and are summarized here.

(1) The technical market need must be considered first. the developed system must be capable of providing the technical or substantial benefit for the sponsor. Therefore, the task to be modelled in the system must be clearly defined. In some universities, many of the tasks chosen for knowledge-based systems are too large or even completely unbounded. The temptation does not come from the market need, but from professor's imagination. Of course, this is inevitable with any new attractive technology. From experts' point of view, however, the task itself should be fairly narrow and domain intensive [10].

(2) If the certainty algorithm has already been very mature in a certain domain, then it is not appropriate for knowledge-based system development. Sometimes, however, it seems necessary to add some knowledge base to a conventional program, such as knowledge-based CAD, to make it more flexible.

(3) If there is no enough expertise in the chosen domain, it is not appropriate for building the knowledge-based system either. According to the development level of artificial intelligence, the learning systems are very weak. It seems impossible to develop a knowledge-based system without sufficient knowledge.

5.2 System Applicability

It is found that, in our practice, to build a demonstration prototype is not so difficult, especially some shells can be available from the soft-ware market. For an applicable commercial prototype, however, much more time and money are really needed. Even some demonstration prototypes could never be developed to commercial types. The investigation shows that the failure reasons may be various, but some of them have been confirmed.

(1) The leader of research group in the front line is not real civil engineer, even there is no civil engineer working in the group. In the project "Intelligent Decision Support Systems in Civil Engineering", three kinds of people, i.e., the civil engineer, the knowledge engineer, and the software engineer must be included in one research group for each subproject. It is so-called "three in one". Usually, the knowledge engineer are very ambitions. They thought they could handle the knowledge in every domain. Couple years ago, many professors and researches spent lots of time to build a number of successful expert systems in China. But now, they are getting tired. they found the conceptualization and the formalization of knowledge is a "bottle neck", which is very difficult for unprofessional experts. Therefore, they prefer to build a generalized shell or to explore some new inference methods. In our project, the relationship between researchers is suggested as Fig.3.

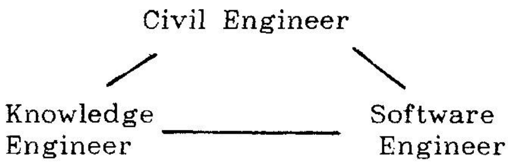


Fig.3

Furthermore, the civil engineer who is doing the knowledge-based subproject is encouraged to learn some general knowledge about knowledge engineering, meanwhile the knowledge engineer is suggested to know some basic concept about civil engineering.

(2) Building knowledge-base is an essential step, but it is often under-estimated in practice. Knowledge can compensate for lack of search. "A man's knowledge consists only of two parts, that which comes from direct experience and that which comes from indirect experience. Moreover, what is indirect experience for me probably is direct experience for other people. Consequently, considered as a whole, knowledge of any kind is inseparable from direct experience" [11]. It is impossible to build a knowledge-base without domain experts.

A knowledge-based system, in general, contains both perceptual knowledge, such as human expertise, and rational knowledge, such as textbook, code, or algorithms. But it should be emphasized here, the rational knowledge depends on the perceptual knowledge. "The rational is reliable precisely because it has its source in sense perceptions, otherwise like water without a source, a tree without roots, subjective, self-engendered and unreliable." "As to the sequence in the process of cognition, perceptual experience comes first,...". On the other side, however, the perceptual knowledge is "...merely one-sided and superficial, reflecting things incompletely and not reflecting their essence. Fully to reflect a thing in its totality, to reflect its essence, to reflect its inherent laws,..." "... it is necessary to make a leap from perceptual to rational knowledge"[11]. In general , a developed knowledge-based system should contain rational or deep knowledge as much as possible.

Any system to be used in commercial practice must be correct to every extent possible. In human knowledge, the process of coming into being, developing and passing away is infinite. Based on the dialectical-materialist theory, "Practice, knowledge, again practice, and again knowledge. This form repeats itself in endless cycles, and with each cycle the content of practice and knowledge rises to a higher level"[11]. Therefore, the name "commercial prototype" is preferable to the " commercial knowledge-based system".

(3) Lack of consideration for expected user. In the United States, people criticise that universities are notorious for they lack an appreciation of what are the real problems facting practising engineers. Somebody expects that 90% expect systems developed in this century will be garbage. In our project, the following points have to be considered: (1) the knowledge level of the intended user; (2) the computer level at which the system performs; (3) the foreign language level of the expected user. In China, microcomputerizing of programs and an interpretation system from english to chinese are needed.

5.3 Building Frameworks (Shells)

Building frameworks or shells are packages that aid in the rapid prototyping of application of knowledge-based systems. They usually provide one, or more, knowledge representation forms and inference mechanisms. Usually, they are domain-independent. When their use is appropriate, these tools can be used to speed up the implementation of new systems. The level of effort that must be applied to developing support structures is greatly reduced. Following the marketing of various shells, as mentioned previously, the knowledge-based systems in civil engineering are increasing rapidly. However, it should be pointed out that there are some limits and disadvantages existing, such as the size limitations, complaxity limitations, awkward representations, inadequate user interfaces, and slow system response times.

Using generalized shells or developing new particular systems directly, which one is the best way especially in the initial stage? From the dialectical theory, the general character is contained in every individual character. "Without individual character there can be no general character" [12]. The cognition process always moves from the particular to the general, and from the general to the particular; each cycle makes it more and more profound. Similarly,we have MYCIN first and then developed the non-domain EMYCIN, now EMYCIN has been used to develop several systems, such as PUFF and SACON. Therefore, it is not necessary to overestimate the domain-independent shell, also do not confine the designers in their own particular system only.

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