CONSTRUCTION APPLICATIONS OF KNOWLEDGE-BASED SYSTEMS

Thomas E. Cooper

Auburn University, Auburn, Alabama, U.S.A.

SUMMARY

Knowledge-based systems (KBS) "enable users with a problem to consult a computer system as they would an expert advisor to diagnose what may be causing a problem or figure out how to solve a problem, perform a task, or make a decision. Like a human expert, such a computer system can extract additional information from the user by asking questions related to the problem during a consultation" [1]. These attributes permit knowledge-based systems to capture relatively scarce expertise and make it widely available to others.

Such systems are generally developed by the use of an expert system "shell" which allows the developer to produce a system with a reasonable expenditure of time and effort. In addition, the use of such a shell generally permits a user with limited computer skills to successfully operate the system.

This paper provides a detailed analysis of the knowledge-based system CLAIMS ADVISOR and a review of the properties, operational features, and capabilities of eleven additional systems. Currently available knowledge-based construction systems include applications in diverse areas with significant capabilities yielding results that often match or exceed those of human experts. Future development of knowledge-based systems can be expected to provide significant opportunity for both the developers and the users of these systems.

KEYWORDS: Knowledge-based Systems, Expert Systems, Computer Applications

INTRODUCTION

A knowledge-based system (KBS) is defined by Mocker and Dologite [1] as "A computer system that attempts to replicate specific human expert intelligent activities." As noted by Turban [2],These systems "are composed of six basic components: knowledge acquisition subsystems, inference engine, explanation facility, interface subsystem, knowledge base management facility, and knowledge base". Of these six parts, only the knowledge base needs to be changed to develop a new expert system. The first five components can be preserved to function as a "shell" to contain and manipulate the knowledge base.

The utilization of a commercially available expert system shell has the potential to allow the developer to produce a functioning system with a reasonable expenditure of time and effort. In addition, the use of one of these shells may also permit the user to develop a system without having to acquire more than a minimal level of programming skill.

According to Waterman [3], the following factors should be considered when determining whether or not such a knowledge-based system is appropriate:

1. The problem should have a symbolic structure, and heuristics should be available for its solution. In addition, it is desirable that the task be decomposable.
2. The task should be neither too easy nor too difficult for the human expert.
3. The problem should be of a manageable size; it also should have some practical value.

A TYPICAL KNOWLEDGE-BASED SYSTEM, "CLAIMS ADVISOR"

A relatively large percentage of the "vertical construction" in the United States is governed by the construction documents developed by the American Institute of Architects (AIA). The evolution of these documents over time has produced a convoluted method of handling the contractor's attempts to receive an equitable adjustment in the contract time and/or contract sum. In addition, the resolution of these claims is further hindered by the complexity of the nation's contemporary legal environment.

Because of the nature of the claims handling process and its significant potential for negative impact upon the contractor, the knowledge-based system "Claims Advisor" was developed. This system was developed to assist a contractor in the evaluation of the relative strength of a construction claim and to serve as a guide through the process of seeking an equitable adjustment in the Contract Sum, the Contract Time, or both.

The Types of Construction Claims

From the perspective of time, claims may be classified as either excusable or non-excusable. In the words of Jones and Wellborn [4], the excusable claims are the result of "a delay for which neither party (contractor or owner) is responsible".The AIA A201 General Conditions document addresses the potential types of excusable delays in paragraph 8.3.1 and the applicable claims procedure in sub-paragraph 4.3.8.1. Sub-paragraph 4.3.8.2. addresses the weather related excusable delays. The increase in the Contract Time may be granted provided that the Contractor provides timely written notice as provided for in sub-paragraph 4.3.8.1. It should be noted that paragraph 8.3.1 indefinitely extends the excusable category with the phrase "or by other causes which the Architect determines may justify delay."

Heuer [5] defines non-excusable claims are those for which "the delaying party (frequently the contractor) has no legally recognized excuse". The AIA A201 document provides for several categories of excusable delay, but it does not specify what constitutes a non-excusable delay.

From the perspective of damages, claims may be classified either as compensable or non-compensable. Oastler, Thompson, and Morse, [6] state that the compensable claim "is designed to reimburse the complaining party for all losses caused and gains prevented". Paragraph 4.3.7 of the A.I.A. A201 document lists seven different categories of compensable claims including one for "other reasonable grounds".

Samuels [7] lists the following three prerequisites in order for a claim to be compensable:

1. an event occurred,
2. it was the fault of some other party, and
3. it cost the claimant money.

Under certain situations, consequential damages may be compensable as well. According to Oastler, et al [6], such damages must meet all of the following in order to be compensable:

1. the resulting damages are reasonably foreseeable,
2. the loss flowed "proximately" from the act, and
3. the amount of the loss can be ascertained.

Development of the Logic Diagram

In the American Institute of Architects (AIA) A201 General Conditions document, section 4.3 deals with CLAIMS AND DISPUTES and section 4.4 deals with the RESOLUTION OF CLAIMS AND DISPUTES. Besides these sections, twenty-five additional paragraphs and sub-paragraphs from the document were identified by the developer as being claims related. From these selected items and from other provisions of the documents that are frequently subject to modification, a detailed logic diagram was developed using the software program *allCLEAR* version 2.0.

The first phase of the system logic diagram addresses the Contract Documents applicable to the project. These considerations include:

1. the identification of the AIA Agreement Form (contract) used,
2. a determination as to whether or not the claim relates to delay, and
3. a determination as to whether or not a "no damage for delay" clause applies.

If the documents do contain a "no damage for delay" clause, the initial phase of the logic diagram also evaluates the chances of that clause being enforced. When a "no damage for delay" clause is enforced, the claim for damages is precluded. In this case, the system offers the user the option of deciding whether the claim for an increase in the Contract Time is to be pursued or the claim is to be abandoned.

The initial phase of the logic diagram produced a total of sixteen possible paths. Fourteen of these paths lead to phase two of the logic diagram and the remaining two paths lead to an appropriate conclusion being provided by the system and the termination of the consultation.

The development of the second phase of the logic diagram addressed the various combinations of circumstances relating to the claim. The basic assumption used in the development of this part of the diagram was that claims are generated because of the occurrence of specific events. The claim is therefore assumed to be the result of one of the following:

1. an action or inaction by others,
2. an occurrence beyond the Contractor's control,
3. a defect in the Contract Documents,
4. the encountering of concealed or unknown conditions, or
5. the occurrence of an emergency situation.

If the selection "an action or inaction by others" is chosen, an additional assumption was made that the party whose action or inaction lead to the claim could be identified as:

1. The Owner,
2. The Architect,
3. The Owner's Forces or Separate Contractor, or
4. A Governmental Agency.

Once these initial selections are made, this phase of the logic diagram may be followed according to the situation or situations applicable to the claim in question. There are a total of 98 possible paths through the second phase with 44 of them leading to the final phase and the balance leading to specific user recommendations based upon the claim's circumstances.

The development of the final phase of the logic diagram included the specific claims handling provisions of the A.I.A. A201 document with particular emphasis on its notice provisions and time limitations. Each of the 34 separate paths through this phase produces specific user advice based upon the required claims handling procedure.

Throughout the Logic Diagram, internal supplemental nodes evaluate the relative strength of the claim, warn the user about specific notice requirements and time limitations, and provide mileposts showing the user's progress through the consultation. The logic diagram provides for a total of 90 advisory conclusions.

Characteristics of the Expert System Shell

This particular knowledge-based system was developed using *EXSYS Professional* 4.0 which is a rule-based program that permits the developer to design and build a system in the Microsoft Windows environment without having to learn either a programming language or to master complicated syntax. *EXSYS Professional* handles degrees of uncertainty with five built-in confidence modes, permitting the developer to select the most appropriate for the system being developed.

EXSYS defines a "qualifier" as a multiplechoice list that generally appears in the IF portion of the rule. For example, qualifier number 5 in the system asks the yes and no question, "IS THE CONTRACTOR'S CLAIM BASED UPON DELAY?". EXSYS permits each qualifier to have as many as 30 values.

"Choices" are defined by *EXSYS* to be the possible solutions from which the expert system will choose in making its recommendation. For example, choice number 4 is "BASED UPON YOUR RESPONSES, THE SYSTEM HAS DETERMINED THAT NO ADDITIONAL ANALYSIS IS JUSTIFIED." Choices generally appear in either the THEN or the ELSE portion of the rule. A completed consultation in *EXSYS* will always end by displaying a choice. When the system's advice is given, the user may end the consultation, review the various inputs, or revise selected inputs and continue the consultation based upon new data.

The IF portion of the rule is generally composed of qualifiers. The appropriate qualifiers and their related values comprise the selected path through the Logic Diagram and are selected in chronological sequence. The Rule Editor has the capability of including choices and other Boolean operators in the IF portion of the rule at the developer's option.

Once the IF portion of the rule is completed, the developer selects the "THEN part" button and indicates the appropriate qualifiers and/or choices required for the THEN part of the rule. The default settings assume that the Boolean operator AND also applies to the THEN portion of the rule. The rule may or may not have an ELSE portion. As with the case of the IF part of the rule, other Boolean operators are available. *EXSYS Professional* permits a rule to have as many as 128 different conditions in the IF, THEN, and ELSE portions of the rule combined.

Operation of the System

If an individual were to consult with a human expert in the field of construction claims, it is reasonable to assume that early in the conversation the expert would ask the following questions:

1. What documents apply?
2. What are the circumstances? and
3. How well have you followed the procedures?

In much the same manner, the typical consultation between the user and Claims Advisor addresses these questions in three distinct phases. In the initial phase, the system guides the user through a review of the Contract Documents and the determination of whether or not a "no damage for delay" is applicable. Since the potential for success of the Contractor's claim is strongly influenced by a claim's surrounding circumstances, the second phase of the system explores these circumstances and advises the user concerning the relative strength of the claim in question. The final phase of the system evaluates the procedures under which the claim in question is to be processed.

The consultation process using Claims Advisor requires between five and fifteen minutes of interaction on the part of an experienced user. This estimate does not include the time required for searching the job records for applicable information necessary to make the appropriate selections. Somewhat longer consultation times are to be expected for inexperienced users.

Evaluation of the System

Once the System was operational, seven typical construction claims cases were selected for the initial evaluation

of the system. In six of these selected cases, the system's conclusion was identical to that of the Appeals Court. In the remaining case, the system's conclusion was opposite to that reached by the Circuit Court, but identical to that reached by the Appeals Court.

Subsequent consultations involving dozens of additional cases confirm the reliability of the Claims Advisor to provide accurate claims related advice to the contractor. In addition, approximately 60 inexperienced evaluators have successfully operated the system without difficulty. Field testing of the system is currently being conducted at 40 universities in the United States, Mexico, Puerto Rico, Korea, and Kuwait.

OTHER KNOWLEDGE-BASED CONSTRUCTION SYSTEMS

USA-CERL Expert Systems

In conjunction with the U. S. Army Construction Engineering Research Laboratory (USA-CERL), Kim and Adams [8] developed a prototype system using Texas Instruments' expert system shell, *Personal Consultant Plus*. The system was developed to evaluate a claim based upon the differing site conditions clause used in Federal construction contracts.

Bridgestock and Robinson [9] have reported on the USA-CERL system for the evaluation of the quality of facility design. This system which is known as BCO Advisor, operates within the expert system shell *KnowledgePro*. The Corps of Engineers normally conducts a Concept Review when the design is 35 percent complete and a Final Review at the 95 percent level. Reviewers of the Contract Documents use the system to serve as a guide through the analysis.

As a refinement of the earlier differing site conditions prototype system, Kim [10] was the principal developer of the USA-CERL Claims Guidance System (CGS). This system is designed to assist Corps of Engineers field and office personnel by providing both para-legal and procedural guidance relative to the "Differing Site Conditions" and "Changes" clauses in Federal Construction Contracts.

Other USA-CERL expert system programs include CASH, a prototype computer assisted scheduling system developed using the knowledge engineering environment *KEE* as reported by Echeverry [11] and CODES, a *KnowledgePro* based prototype estimating system as reported by Sun, Rao, Echeverry, and Kim [12].

PAVE, an Expert System for the Identification of Causes of Failure of Asphalt Concrete Pavement

Kuprenas, Salazar, and Posada [13], have developed a rule-based system to determine the root cause of failures in asphalt concrete pavements. This system, developed using the expert system shell *VP Expert*, is intended to guide personnel employed by the public works departments of governmental agencies in assessing pavement failures.

From the available knowledge of experts, the paving failures were divided into the three categories of: failure caused by surface defects, failure caused by surface deformations, and failure caused by the cracking of the pavement. The system has the capability of permitting the user to employ appropriate confidence factors to the variables during the consultation.

According to the developers, "The advantages of PAVE are the simplicity of its knowledge base structure, relative ease of identification of asphalt pavement failure types, and the ease of use of the system itself". Future development of the system is expected to provide for the refinement of the failure mode identification process and the incorporation of fuzzy logic capabilities.

CONSAFE, a Construction Safety Expert System

Kak, Zacharias, Minkarah, and Pant [14], have developed a system to "help the construction manager to plan and safely execute earthwork, reduce environmental hazards, recommend appropriate personnel protective and life safety equipment, and prevent fall accidents". This system was developed by incorporating the current regulations of the Occupational Safety and Health Administration (OSHA) and other federal agencies and national organizations. The developers elected to build the system using the expert system shell *Guru* with the programming being done using Knowledgeman Guru Language (KGL).

Safety related aspects of the construction environment were divided into the categories of construction equipment, temporary structures, electrical systems, construction operations, and occupational health and environmental controls. Individual rule sets were then developed for each of the categories and input using *Guru's* rule set manager. Once the system was operational, field testing was conducted at project sites and in educational institutions. Favorable responses have been reported from the users who indicate that the average consultation was concluded within 30 minutes.

RIS, an Expert System for Preventing Radon Entry into Houses

Radon is a gas produced by the radioactive decay of radium which emits alpha particles that can produce lung cancer. The information related to radon exists in scattered locations and is largely subjective in nature. Li, Al-Ahmady, and Najafi [15] gathered this information and incorporated it into an overall system that links a spreadsheet, a database, a word processor, and an expert system shell. For their operating system, the developers elected to use the software *HyperCard* based upon its graphical presentation ability and its capability of providing object-oriented programming in conjunction with the expert system shell *MacSmarts*.

The developers combined the information available from the Environmental Protection Agency (EPA) and the Florida Radon Research Program (FRRP) with contemporary mitigation methods into a homeowner data base, a contractor database, and a researcher database. The contractor database is further subdivided into a section dealing with indoor radon prevention and a section dealing with mitigation methods. Consultation by use of the RIS system provides the user with diagnosis and prediction of the indoor radon levels as well as Constructability and cost data.

FLSDS, an Expert System for Military Horizontal Construction

In military operations, construction time may be limited by a host nation or by the critical need for the combat facility. The Flight Landing Strip Design System (FLSDS) was developed by Beidermann, Weber, Bashford, and Mayo [16] at Arizona State University to assist the military engineer in the design of temporary air strips.

Army and Air Force technical manuals provide the military design methods and standards, but may not be available in critical situations or may contain information that is difficult to interpret under the time constraints. In addition, the field engineer may have limited experience in the design of facilities of this type. Stated goals of the system are: to reduce the design time for new construction, repair, or maintenance of flight landing strips, to reduce the learning curve for flight landing strip design by inexperienced engineers, and to demonstrate the applicability of expert systems to military engineering.

To meet these needs, the developers linked five knowledge bases together using the expert system program *VP Expert* version 3.1. The DIM database contains the dimensional data, the DIM1 database provides the graphical presentation capabilities, the SORTIES database deals with the number of landings that the sub-base can withstand, the CBR database deals with the soil characteristics, and the FLSDS database ties the other databases together.

Evaluation of the design recommended by the FLSDS system by twelve experienced military engineers concluded that the system was fast and accurate and its success justified future development of additional military expert systems.

CPPS, an Expert System for Planning and Delivery of Reinforcing Steel

In the United States, the process that leads to the installation of reinforcing steel in concrete structures consists of five distinct steps: ordering, detailing, fabrication, delivery, and placement. Traditionally, the rebar fabricator provides the detailing, fabrication, and delivery services.

Recognizing the potential for improvement in the process, Salim [17] has integrated *AutoCAD, dBASE*, and *LEVEL 5 OBJECT* software into a system for "Intelligent Process Planning" which attempts to optimize the installation procedure. In this system the user picks standard bar configurations from the library and inserts the pre-designed unit into the design drawing. Frame-based attributes then permit the designer to specify the balance of the required information such as bar size, length of critical section, etc.

Once the design and detailing operations are completed, the specific packaging scheme is developed to optimize both the rebar fabrication and their field placement. A six story building with four identical floors was selected for field testing of the system. The second and third floors were constructed using traditional methods for bundling, delivery, staging, and placement. The fourth floor used the system-designated placement planning concept and the fifth floor used a hybrid of the traditional and system-designated concept. Crew productivity ratings for the second and third floors were observed to be 24.8% and 27.8% respectively while crew productivity for the fourth and fifth floors was 54.9% and 43.5% respectively. Implementation of the system-designed placement planning concept resulted in more than doubling the crew productivity!

Flat Roof Diagnostic System

Allwood and Goodier [18] have constructed a system to diagnose defects in flat roofs having 276 goals and over 1,000 rules. This system was developed in collaboration with a large number of governmental and industrial experts and uses the expert system shell *XiPlus*.

The initial development of the system was based upon dividing all of the observed problems into three broad categories based upon the type of roof deck utilized. Then the emphasis was directed toward defects that affected each layer of the assembly, defects affecting the entire assembly, and defects resulting from penetrations through the roof.

Diagnosis of the roof problem begins with the system asking the user for input as to the source of the water which may be: rain penetration, condensation, built-in water, leakage at roof penetrations, or non-leakage problems such a ponding. As the consultation proceeds, the system requests other input to define the scope of the problem and provides help to assist the user in providing the proper response.

Once the system was developed, seventy-nine tests were made with the system output producing near 100% accuracy. In blind tests, twenty of the problems from the field trials were submitted simultaneously to the system and a panel of human experts. In each case, the computerized system scored as well or better than the human experts!

THE FUTURE OF CONSTRUCTION RELATED KNOWLEDGE-BASED SYSTEMS

Construction related Knowledge-based systems hold real promise for the future. A system is currently being developed to generate Contractor / Sub-contractor Agreement forms that are custom tailored for the project and contain specific legal language for each of the States in the southeast portion of the United States. Another system is under development that will integrate the selection of the mix proportions and the thickness design of asphaltic concrete runways for both military and civilian airports.

If the procedure is complicated, the expertise is scarce, the consequences of an incorrect decision are great, uniform conclusions are desired, and the time for decision making is limited, Knowledge-based systems have significant potential.

REFERENCES

1. **Mocker, R. J. and Dologite, D. G.** *An Introduction to Expert Systems*. Macmillan, New York, NY 1992
2. **Turban, Efraim** *Expert Systems and Applied Artificial Intelligence*. Macmillan, New York, NY 1992
3. **Watterman, D. A.** *A Guide to Expert Systems*. Addison-Wesley, Reading, PA 1985

4. **Jones, G. W. and Wellborn, P. F**. Delays. *Common Sense Construction Law : Avoiding and Resolving Claims*, 1993, Chapter IX
5. **Heuer, C. R.** *Means Legal Reference for Design and Construction*. Means, Kingston, MA 1989
6. **Oaster, B. R., Thompson, P. A., and Morse, L. P.** Claims and Proof of Damage. *Common Sense Construction Law : Avoiding and Resolving Claims*, 1993, Chapter XII
7. **Samuels, B.** *Construction Law*. Prentice-Hall, Englewood Cliffs, NJ 1994
8. **Kim, M. P. and Adams, K.** An Expert System for Construct Contract Claims. *Microcomputer Knowledge-based Expert Systems in Civil Engineering*, 1988
9. **Bridgestock, G and Robinson, P.** *BCO Advisor System* [computer program] USA-CERL, Champaign, IL
10. **Kim, M. P.** *CGS Claims Guidance System* [computer program] USA-CERL, Champaign, IL
11. **Echeverry, D**. *Factors for Generating Initial Construction Schedules* [dissertation] Department of Civil Engineering, University of Illinois, 1990
12. **Sun, R., Rao, G., Echeverry, D., and Kim, S**. A Prototype Construction Duration Estimating System (CODES) for Mid-Rise Building Construction, *Interim Report USA- CERL*, March 1991
13. **Kuprenas, J. A., Salazar, R., and Posada, R.** An Expert System for the Identification of Causes of Failure of Asphalt Concrete Pavement. Proceedings of the Second Congress of Computing in Civil Engineering, Atlanta, Georgia, June 5-8, 1995 pp. 582-588
14. **Kak, A., Zacharias, K., Minkara, I., and Pant, P** A Knowledge-based Software for Construction Safety. Proceedings of the Second Congress of Computing in Civil Engineering, Atlanta, Georgia, June 5-8, 1995 pp. 997 1002
15. **Li, W., Al-Ahmady, K., and Najafi, F.** Expert System Application in Construction for Preventing Radon Entry into Houses. Proceedings of the Second Congress of Computing in Civil Engineering, Atlanta, Georgia, June 5-8, 1995 pp. 1003-1010
16. **Biedermann, R., Weber, S., Bashford, H., and Mayo, R.** Development of a Expert System for Military Horizontal Construction Operations. Proceedings of the Construction Congress, San Diego, California, 1995. pp. 528-535
17. **Salim, M.** Process-Oriented Intelligent Planning for the Delivery of Reinforcing Bars. Proceedings of the Second Congress of Computing in Civil Engineering, Atlanta, Georgia, June 5-8, 1995 pp.358-364
18. **Allwood, R. J. and Goodier, A.** Development of a Practical Knowledge-based Advisor to Diagnose Defects in Flat Roofs. Proceedings of the Second Congress of Computing in Civil Engineering, Atlanta, Georgia, June 5-8, 1995 pp. 365-372