Advantages of the interactive system

The interactive strategic expert system gives more appropriate results, for the cases of users tested, than the minimally interactive expert system. This interactive strategy expert system is not only appropriate for different individual uses, but could be utilized by several different whole categories of users because of its varied levels of information. Each of the choices are displayed visually, their impact on other choices traced, their attributes explained, and most importantly, a complete, in depth, written and visual description can be given. The latter may serve to train someone to actually design or build a chosen structure (a video could also be developed for that purpose). Thus, the system can be used by management to select any materials and building techniques in accordance with the various constraints, by military field officers to make decisions and build with the following guidelines, and by laborers, trainees or owner/builders to use as a training device. (Of course, the topics for choice making may be different for different these groups of users.)

In terms of computer time and money necessary to develop an interactive working expert system, one needs several years and $150,000 - $200,000 according to the expert systems division people at Texas Instruments. This is the major disadvantage of such an interactive mode, the main advantage being that everyone using it, at whatever level in a hierarchy, has access to expert knowledge and can make good decisions.

Perhaps the most surprising benefits of an expert system are those accrued by the person who designs an expert system. He or she, of necessity, must carefully clarify his/her understanding. The expert/designer must: 1) already know or else learn the field very well and be able to explain it, 2) see clearly the areas of conflict or contradiction in the knowledge, 3) identify the areas without enough knowledge, and 4) find those areas needing research.

REFERENCES

Bennett, J. L. Creary, R. Englemore, and R. Melosh, "SACON: A Knowledge Based Consultant for Structural Analysis," Standford University, Report No. STAN-CS-78-699, (September 1978).

Gevartner, W.B. "An Overview of Expert Systems," NBSIR 82-2505, prepared for the National Aeronautics and Space Administration, (May 1982).

Givoni, B. "Design for Climate in Hot, Dry Cities," to be a chapter in a forthcoming book Passive Cooling of Buildings, McGraw-Hill.

Koeningberger, O., T.G. Ingersoll, A. Mayhew, and S.V. Szokolay, Manual of Tropical Housing and Building, Part I, Climatic Design, Longman, Inc., New York, (1973).

Landsdown, J. "Expert Systems: Their Impact on the Construction Industry," Report to RIBA Conference Fund, (1982).

Waterman, D.A. and F. Hayes-Roth, "An Investigation of Tools for Building Expert Systems," prepared for the National Science Foundation, R-2818-NSF, (June 1982).

A Knowledge Engineering Approach to the Analysis and Evaluation of Vertical Construction Schedules

Jesus M. De La Garza and William Ibbs

University of Illinois at Urbana-Champaign
Newmark Civil Engineering Laboratory
208 North Romine Street
Urbana, Illinois 61801
U. S. A.

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ABSTRACT

The success of any construction project relies heavily on the manager's ability to identify and synthesize diverse factors, to form judgments, to evaluate alternatives, and to make sound decisions. In sum, to apply years of experience and acquired wisdom to the problem at hand. The objective of this knowledge engineering project is to extract, formalize, and articulate the construction expertise needed to develop a useful, intelligent computer system. The primary goal is to emulate the reasoning process of experienced project managers in the context of construction schedule analysis. This knowledge base consists of scheduling decision rules, construction common sense knowledge, and construction knowledge developed or used by experts when planning a project. The system's development environment includes a LISP machine, which houses an expert system shell and a relational database management system, and a Personal Computer, which hosts a project management system.

Une manière d'analyser et èvaluer le maniement des connaissances des plans verticals de construction

Jesus M. De La Garza and William Ibbs

University of Illinois at Urbana-Champaign
Newmark Civil Engineering Laboratory
208 North Romine Street
Urbana, Illinois 61801
U. S. A.

MOTS CLÈS

Construction, Intelligence artificielle, Maniement de la construction, Plan de construction, Systèmes experts

ABSTRAIT

Le succès de n'importe quel projet de construction fait fond principalement sur la capacité du directeur d'identifier et consolider divers facteurs, faire des jugements, èvaluer des alternatives, et prendre des bonnes décisions. En résumé, il faut mettre en pratique des années d'experience et de la connaissance acquise, sur le problème en analyse. L'objectif du projet de recherche dans le domaine de la formalisation du savoir ("knowledge engineering research project") est d'extraire, de donner une forme, et d'articuler l'expertise de la faculté formative qui est nécessaire pour développer un système intelligent et utile. Le but principal est de simuler le raisonnement des directeurs de projet expérimentés en analyse de plans de construction. Cette base de connaissance consiste de règles de décision pour la planification, du sens commun appliqué à la construction, et de la connaissance de construction développée ou utilisée par un expert en train de planifier un projet. L'environement pour développer le système, inclue un ordinateur qui use le language LISP, et qui contient l'infrastructure d'un système expert ("expert system shell") et un système de maniement du "database" relatif ("relational database management system"), et un ordinateur personnel ("Personal Computer") qui contient un système de maniement de projets.

INTRODUCTION

Integrated project management expertise about design, construction, economic, social and political issues plays an increasingly important role in the proper execution of construction projects. Although computers have become indispensable tools in many endeavors, they have only succeeded in solving problems that have algorithmic or closed form solutions and in supplying enormous amounts of valuable data. Computers, however, have not been successful at providing facilities for the qualitative and subjective interpretation of such data. The construction industry ultimately relies upon human experts to interpret these data and make sound decisions. In sum, the application of the project manager's years of experience to the project at hand. This is especially true regarding construction project management in which experience and subjective judgment play a major role.

Artificial Intelligence (AI) technology provides a way to capture and replicate empirical judgmental knowledge in the form of computer programs called Expert Systems (ES). Several researchers have pointed out that the nature of the construction industry makes these expert systems especially applicable to construction engineering and management [1]. Frames, rules and logic are the three basic architectures for building such expert systems [2,3,4]. A frame-based expert system allows the developer to organize the knowledge base into a hierarchical taxonomy of frames. The inheritance mechanism built into these systems provides the main means for inferring. In a rule-based system, the knowledge base consists of self-contained pieces of knowledge in the form of "if ... then" rules. Rule-based systems are characterized by forward and backward chaining inference mechanisms. Finally, the knowledge base in logic-based systems consists of a set of objects and predicates. Quantifiers and logical connectives are applied to these objects and predicates to form relationships. The theorem-prover inference mechanism insures that all and only valid consequences are asserted. The art of crafting expert systems is called Knowledge Engineering.

The objective of this knowledge engineering research project is to extract, formalize, and articulate construction expertise to develop a useful intelligent system whose primary goal is to emulate the reasoning process of experienced project managers in the context of construction schedule analysis.

STATE OF THE PRACTICE

The construction schedule problem domain is characterized by the use of expert knowledge, judgment and experience. Traditionally, project managers use a set of key indicators and exception reporting mechanisms to assess the status of the project under development. These indicators are taken both from the data generated by project management systems (PMS) and from several other relevant, external sources (e.g., the state of economy, bid competition, corporate goals, etc.). These key indicators are not usually isolated or brought to the project manager's attention by the PMS. Instead they are formed by combining the relevant attributes of the project itself with experimental judgmental knowledge of the project manager.

PMS are an excellent means to process project information, to find the optimum timing of every milestone, and to summarize project data. They do fall short in many regards, though. For example, PMS do not reason about the information they are processing; they do not recognize that "roofing" should not be scheduled during winter if ambient temperatures are expected to be below specified minimums; PMS do not complain when an activity such as "installation of the air conditioning unit" is not preceded by the procurement of such equipment; and they do not assess the causes for lagging construction. Equally important, the construction knowledge necessary to create the schedule is lost as it is not transmitted to the project manager using the network. If an intelligent system can provide the expertise that knowledgeable project managers use to evaluate schedules, then other less experienced individuals can better assess the correctness, efficiency, and soundness of a given project schedule.

STATE OF THE ART

Progress towards the building of an expert system for the analysis and evaluation of construction scheduling networks from an owner's perspective has already been reported [5]. This expert system is fully implemented by linking together database, project management and expert system technology on a single personal computer.

Attempts to represent not only project management knowledge, but also claims legal expertise with rules of an "if ... then" form, as well as with the use of frames have been proven successful by other researchers [6,7,8,9]. None of these intelligent computer systems, however, has access to a database containing information already known about the project. Such information is most likely available on electronic databases from other project management programs. Having to re-input this same attribute information, for each activity in a large network, defeats the usefulness of any system deployed at the construction site.

Being able to identify the possible causes for lagging construction is only the first step towards simulating the decision-making process of experienced project managers. "What if" scenarios, based on the results obtained in this first phase, form the basis for exploring, merging, and eliminating hypothetical alternatives [10,11,12]. A project planning system for the design and construction of an oil drilling platform has taken a similar approach. It represents anticipated contingencies such as different combinations of soil types and labor conditions, and then reasons the effects of these factors on the cost and duration of the project [13].

KNOWLEDGE ACQUISITION

Knowledge acquisition is perhaps the most ambitious, important, time-consuming, ill-structured, and challenging phase of this knowledge engineering effort. The authors also believe that in the knowledge lies the power of the system.

The nature of the Construction Industry is such that the knowledge about construction schedule control, even for the same type of project (e.g.,

high-rise reinforced concrete buildings), is not found in a single human expert. Thus, it is important to find and use knowledge from multiple experts. The advantages of using a diverse collection of experts, as outlined in [14], more than offset the extra time required to resolve conflicts and contradictions generated by them.

Our approach to knowledge acquisition is based on the methodology described in [15] and consists of following three steps: 1) Familiarization; 2) Organization of the knowledge; and 3) Representing the knowledge.

Two main techniques are utilized to extract and formalize the experts' knowledge: 1) Experts give an account of their expertise by describing how they go about evaluating the goodness of a network and assessing the causes for lagging construction; 2) Experts exercise their expertise on real problems, and then a model replicating their approach is generated and tested.

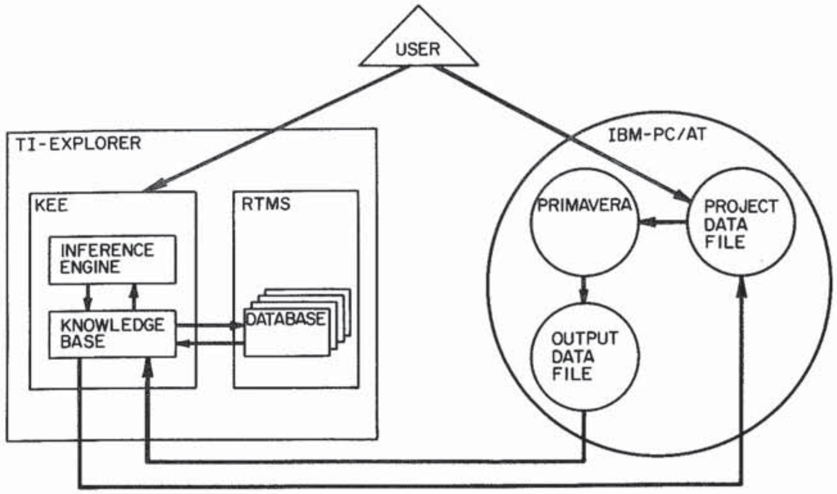
THE EXPERT SYSTEM ENVIRONMENT AND ITS OPERATION

A basic expert consists of the knowledge base, the inference engine, and the user. The trend however, is toward more complex, sophisticated, and integrated systems like the one shown in Fig. 1. The benefits of linking together database, project management, and expert systems technology to help make optimal use of the data and to assist the project manager in the interpretation of that data, far outweigh the complexity and cost of its implementation.

As shown in Fig. 1, this development environment consists of two computers: a) An IBM-PC/AT hosting PRIMAVERA^{Tm}; and b) A TI-Explorer LISP machine housing the Knowledge Engineering Environment (KEE^{Tm}) and the Relational Table Management System (RTMS^{Tm}). KEE is a set of software tools designed to assist system developers in building expert systems; RTMS is a LISP-based relational database; and PRIMAVERA is a highly interactive microcomputer based project management system. Communication between the two computers is established across a serial line (RS232 port).

When KEE first requests information about the project, it opens communication to the external PRIMAVERA program, waits for the results, stores them in a database within RTMS, and starts processing. Upon KEE's request, standard user-supplied initial schedule or project progress data are processed by PRIMAVERA to generate several customized reports. This output contains the minimum project information from which inferences and alternative scenarios are explored. After this operation is completed, a set of rules in the knowledge base is triggered to retrieve each activity from the RTMS and assign it to the corresponding frame(s) (e.g., CONCRETE, ELECTRICAL, MECHANICAL, ACTIVITY, WEATHER-SENSITIVE, etc.).

At this point the evaluation of the network continues. Should the inference engine modify activity attributes whose effect on the project can only be estimated by re-calculating the network, then the knowledge base creates a new database in RTMS. It then sends the PRIMAVERA program the new information to process, waits for the new results to return, inserts the new results into



KEE^tm is a set of software tools for building expert systems.
RTMS^tm is a relational database
PRIMAVERA^tm is a project management system

Figure 1 The Expert System Environment

the appropriate frames in KEE's knowledge base, and continues processing. There are, thus, no limits on the data that can be sent across the communication link between the two computers, with KEE still maintaining control.

THE KNOWLEDGE BASE

The knowledge base consists primarily of scheduling decision rules, construction common sense knowledge, and construction knowledge developed or used by the experts when planning a project. Each of these modules is illustrated by means of a simple example.

The scheduling decision rules assure that the construction network complies with general requirements, logic, time, and cost constraints imposed by the owner. For example, if the project schedule has been front-end loaded, the knowledge base searches for activities that are either planned near the start of the project and their cost-per-day ratio exceeds the 90^{th} percentile, or activities that are scheduled near the completion date whose cost-per-day ratio is less than the 10^{th} percentile. This analysis may be invoked on activities of a common trade or on activities across all trades.

Construction common sense knowledge includes the ability to detect lagging activities belonging to a single trade and to modify the duration of all members of this trade whose status is unfinished. Lagging activities are only those experiencing slower than anticipated progress. A similar approach is followed for activities having a faster that planned progress.

At the time the project is planned, special attention is assigned, for example, to the correct timing of winter-sensitive activities. Whenever there is a change in the start or finish of any of these activities, a project manager usually runs a new verification. KEE accomplishes this by assigning a set of rules that understand weather related constraints to the frames representing these activities. As soon as the start and/or finish value is modified, these rules are fired to assure the new timing is within reasonable limits.

CONCLUSIONS

Since even human experts tend to overlook factors now and then, the use of AI in the Construction Industry as an intelligent assistant to the project manager can assure an efficient and reliable interpretation of data. Furthermore, the use of this expert system by contractors will certainly relieve the project manager's thought process of the routine and tedious phases, which are necessary during scheduling network evaluation and frequently areas where errors do arise.

Applications such as the subject of this paper can also be used to capture and preserve valuable corporate expertise in a form that can be widely disseminated. Plans are to make this system available to a much wider audience by employing announced plans to install KEE at the personal computer level (IBM-PC/RT).

REFERENCES

1. C. W. Ibbs, Proceedings of a Workshop for the Development of New Research Directions in Computerized Applications to Construction Engineering and Management Studies, University of Illinois, Construction Research Series Tech. Rept. 19, (1985).

2. R. Fikes and T. Kehler, "The Role of Frame-Based Representation in Reasoning," Communications of the ACM, 28, (9), pp. 904-920, (1985).

3. F. Hayes-Roth, "Rule-Based Systems," Communications of the ACM, 28, (9), pp. 921-932, (1985).

4. M. R. Genesereth, and M. L. Ginsberg, "Logic Programming," Communications of the ACM, 28, (9), pp. 933-941, (1985).

5. M. J. O'Connor, J. M. De La Garza, and C. W. Ibbs, Jr., "An Expert System for Construction Schedule Analysis," Proceedings of the Expert Systems in Civil Engineering Symposium, ASCE, (Seattle, WA, 1986).

6. R. E. Levitt, and J. C. Kunz, "Using Knowledge of Construction and Project Management for Automated Scheduling Updating," Project Management Institute, 16, (5), pp. 57-76, (1985).

7. M. R. McGartland, C. T. Hendrickson, "Expert Systems for Construction Project Monitoring," Journal of Construction Engineering and Management, ASCE, 111, (3), pp. 293-307, (1985).

8. L. B. Nay, and R. D. Logcher, "An Expert System Framework for Analyzing Construction Project Risks," Tech. Rept. CCRE 85-2, MIT Department of Civil Engineering, (1985).

9. J. E. Diekmann, and T. A. Kruppenbacher, "Claims Analysis and Computer Reasoning," Journal of Construction Engineering and Management, ASCE, 110, (4), pp. 391-408, (1984).

10. C. Williams, "ART - The Advanced Reasoning Tool: Conceptual Overview," Inference Corporation, (Los Angeles, CA, 1985).

11. B. D. Clayton, "ART - Programming Tutorial," Inference Corporation, (Los Angeles, CA, 1985), Vol. 2.

12. IntelliCorp, "KEE 3.0 - The Knowledge Engineering Environment Technical Summary," IntelliCorp, (Mountain View, CA, 1985).

13. J. C. Kunz, T. Bonura, R. E. Levitt, and M. J. Stelzner, "Contingent Analysis for Project Management Using Multiple Worlds," Proceedings of the First International Conference on Applications of Artificial Intelligence to Engineering Problems, (Southampton United Kingdom, 1986).

14. S. Mittal, and C. L. Dym, "Knowledge Acquisition from Multiple Experts," AI Magazine, 6, (2), pp. 32-36, (1985).

15. M. Freiling, J. Alexander, S. Messick, S. Rehfuss, and S. Shulman, "Starting a Knowledge Engineering Project: A Step-by-Step Approach," AI Magazine, 6, (3), pp. 150-164, (1985).