The use of expert systems, hypertext and spreadsheets in construction
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Abstract

The proliferation of the use of the microcomputer in the 1980s created the development of many different computer based systems in the construction industry.

The paper presents three computer based information systems which have been developed by the Construction Engineering and Management Group at the University of New Brunswick, Canada. The systems which include the use of hypertext, expert systems and spreadsheets are briefly described. Knowledge elicitation and the required extent of the user’s knowledge is covered in more detail. A brief review of the application of the systems is made, including the role that AI played, before conclusions are drawn.

1 Introduction

The widespread acceptance of the microcomputer in the early 1980s created a search for ways in which this new tool could be used by construction engineers. Since then, new high technology has been introduced or developed such as virtual reality, the use of Artificial Intelligence (AI), the internet and other information technology. The conventional methods still used in the construction industry appear to
inadequately provide the means for effectively storing and manipulating the colossal amount of data and knowledge which typifies the fragmented industry.

Several computer based systems have been suggested by research teams which enable the collective knowledge and experience of many experts to be collated and used as Artificial Intelligence (AI) decision support tools in construction management procedures. However, a certain credibility gap exists between the fairly reluctant conservative practitioners and the research teams advocating new methods.

For a long time the construction industry has been a major user of machines to assist humans in physical ways. Now computers are being used to out-perform humans in mathematical tasks and decision making processes. Artificial Intelligence, which encompasses the field of expert systems and neural networks is an area of computer science which attempts to create computer systems which can simulate human intelligent behaviour and even out-perform humans. Hypertext is also used for text retrieval. There are similarities between hypertext and expert systems. Simple rule-based expert systems can be expressed diagrammatically as decision trees. This structure can also be used by hypertext.

The scope of this paper is to present three computer based information systems which have been developed, using Artificial Intelligence, by the Construction Engineering and Management Group at the University of New Brunswick and to show, in a small way, how systems can be applied to construction tasks, and also explain to what extent knowledge and data can be stored in the systems as compared to the knowledge and experience required by the user of a system. The three examples which are described utilize the following:

1) Hypertext
2) An Expert System
3) Spreadsheets and Hypertext.
2 Computer Based Information Systems Using Acquired Knowledge

The three examples cover:
1) A hypertext system to assist in the processing of construction contract claims.
2) An expert system which can be used for the selection of appropriate earthmoving equipment and the estimation of their productivity and costs for earthmoving operations.
3) A system capable of assessing the amount of risk in construction schedules by utilizing hypertext and spreadsheet programs.

2.1 Hypertext

Work by Bubbers [1] used hypertext to assist in the processing of construction contract claims. Since the introduction of Hypercard by Apple in 1987 several other hypertext shell programs have been released both for Apple Macintosh and IBM PC type microcomputers. Hypertext is a method of text retrieval.

Rather than using conventional text which is designed to be read linearly from start to finish, hypertext consists of a collection of non-sequential text items or nodes. In hypertext, access to information is provided by links from one node to another. Jumps from one node to another are accomplished by activating the desired link, usually by selecting it with a mouse. Links are indicated within nodes usually by highlighting a word which is relevant to the node to which it leads.

Hypercard would have been an obvious choice of shell to use in this research since it is the program which popularized hypertext and was provided at no extra cost by Apple. However, IBM compatible personal computers are much more prevalent in the construction industry, and so a program which would run on this type of hardware was considered more appropriate. Only two hypertext shells were readily available for IBM type computers when the search was made. HyperPad was chosen.

Since the search was made, several other shells have appeared on the market, mostly as applications that run under “Windows” on IBM type personal computers.

2.2 Expert Systems
Work by Xie [2] developed an expert system for the selection of appropriate earthmoving equipment and the estimation of productivity and costs.

The essential features of an expert system are characterized by four properties: expertise, symbolic reasoning, depth, and self-knowledge (Waterman [3]; Allwood [4]).

1) Expertise
An expert system must contain the knowledge of a specific domain and apply this knowledge to produce solutions.

2) Symbolic Reasoning
Domain knowledge is presented in an expert system by sets of symbols, and symbols are strings of characters that stand for a real-world concept.

3) Depth
An expert system operates in a relatively narrow domain, but reaches solutions to difficult problems. The problem domain is represented by a set of “IF ... AND ... THEN ...” rules in a rule-based expert system.

4) Self-Knowledge
An expert system not only contains domain knowledge, it also has the knowledge that examines and justifies its own reasoning, and explains its operation by an explanation facility.

In the early stages of expert system development, computer programming languages were often used as expert system building tools. Traditional computer programming languages, such as FORTRAN and PASCAL, proved to be not well suited to develop expert systems. Symbol-manipulation or logic programming languages, such as LISP and PROLOG, were then more often used because of their features: flexible symbol manipulation, sophisticated editing and debugging aids, and other capabilities.

Following these developments easy-to-use shell programs became more popular as expert system building tools. A shell program is a computer software package that generally contains a set of knowledge representation schemes, an inference engine, facilities for storing knowledge and linking with other software packages such as spreadsheets or databases. It provides not only the working environment to the expert system developer but also the interfacing channel to the end user. The relative simplicity of use is one of the main advantages of shell programs. This enables professionals in construction engineering to develop expert
systems even though they do not possess a background in AI.

The shell program chosen for developing the system was the EXSYS Professional shell program (EXSYS [5]).

2.3 Hypertext and Spreadsheet Programs

Mulholland [6] used hypertext and spreadsheets to develop a system for the assessment of schedule risk. Previous research efforts had demonstrated that hypertext software systems can provide an electronic document information system in some ways superior to a traditional document management system.

In construction there is a lack of information documenting past project experiences, particularly for large projects. The system developed provides a means to capture and store historical risks and to make information readily available as AI for future project teams. The research involved the use of a Hypertext system to store and access large amounts of heterogeneous documentation. The system therefore acted as a medium to provide background information concerning previously experienced schedule risks.

An Apple Macintosh computer and Hypercard software were selected to store and provide an effective interface to quickly locate and display information because this type of computer was used in the office where the system was developed. For the same reason, the Excel spreadsheet was the tool used for determining the effects of the risks on the project performance time.

3 Extent of User’s Knowledge - Knowledge Elicitation

In the use of Hypertext for construction claims the choice of which text should be included depends on the system developer. The system developer can sometimes call on many experts to determine which case histories should be included. For other links, when the description is, for example, a clause in a specification, the choice is obvious. The extent of the user’s knowledge need only be limited. Often in the systems which have been developed the user cannot easily determine where alternative paths would have led if she had answered the computer’s questions
differently. Admittedly, there are often explanation facilities, but they are hardly appropriate if the user is experienced enough to be able to defend and justify decisions that are made. A hypertext system can inform the user of the rights and obligations contained in the contract conditions. The hypertext nodes guide the user to relevant information contained in various documents. The system can inform less experienced users what constitutes reasonable costs and is capable of presenting the user with contrary opinion thus making the user aware that claim decisions in construction are not always straight forward.

In the development of the expert system for construction equipment selection, knowledge acquisition was time-consuming and complex. Knowledge of earthmoving is sometimes difficult to elicit completely. This imposes certain limitations on the use of expert systems. The goal of the research was to develop an expert system which contains the common knowledge of experts on the routine selection and estimation of earthmoving equipment so that this knowledge could be used as AI in the system.

The selection of earthmoving equipment and the estimation of its costs rely heavily upon human experience and knowledge. The body of knowledge of earthmoving is available in the industry in general, however, in particular companies such experience and knowledge may be incomplete, discrete or inconsistent because of personnel limitations. Such limitations can be overcome by an expert system incorporating the knowledge from a wider range of domain experts. As a decision support tool, an expert system in earthmoving can assist an earthmoving planner, especially one who is less experienced. Even a skilled planner may benefit from such an expert system as it can reach a quick solution that can be used as a reference or a datum particularly in sensitivity analyses.

In the research, a questionnaire was first developed, on the basis of a literature review, discussion with experts, and self-experience, in order to gather realistic knowledge of earthmoving. The questionnaire was divided into three parts: machine selection related, production related, and cost related. Questionnaires were then sent to contractors in the Province of New Brunswick for input and also for advice on how to further develop and enhance the questionnaire. The questionnaire was then modified and sent to companies in Canada and the United States.

In addition to the questionnaires, interviews, including telephone interviews and personal interviews, were also conducted. Further
contacts were made with the respondents to obtain more details to some of their answers. To refine knowledge, interviews with experts in local companies, including equipment companies, were conducted. The combined body of knowledge from all sources was then implemented as AI into the expert system developed.

In the work on assessing risk in construction schedules, the research was done in three phases. The first phase employed an in-depth review and analysis of papers and articles concerning traditional project scheduling processes.

The second phase of the research involved the development of a list of schedule-related risk factors typical of construction projects. The list was compiled from an extensive survey of sources of project experience. The first source was the work done by NB Power to identify and eliminate problems in the proposed construction of a second nuclear unit at the Point Lepreau Nuclear Generating Station. A comprehensive review of current literature focusing on articles that addressed schedule success and failure criteria was the second source. A third information source was a series of reports concerning the state of the US construction industry produced by the Construction Industry Institute.

The third and final phase of the research involved the review and selection of two risk analysis technologies:
1) Risk identification and measurement processes, and
2) Computer technologies to support the execution of these processes.

4 Application of Systems

Examples of nodes in the application of the Hypertext system for construction claims are shown in figure 1.

The system enables the user to select a particular subject and click on to various different nodes to learn more about a specific clause in the text. The AI contained in this system guides the user to relevant information by links from one node to another and assists in the processing of construction claims.

Samples of the screens are shown in figures 2 and 3 in the expert system for construction equipment selection. The amount of knowledge elicited for just one screen in the system can be demonstrated by the “type of operation” screen shown in figure 2. To acquire knowledge regarding
the type of machine versus the type of operation, and to implement the AI in the expert system, a rating system for selecting machines that are suitable for each operation was developed. Machines were weighted according to their appropriateness to each type of operation. The scale ranged from 0 to 10. The average of weighted values from responses to the questionnaire was used for rating the machines in the system. The use of AI therefore enables the appropriate selection of a machine type to be made. Other AI was used in the system to assist the user in the choice of machine sizes and for machine matching.

The structure of the hypercard knowledge base in the risk identification system is shown in figure 4. Figures 5 and 6 demonstrate the use of the spreadsheet in modeling schedule risk. AI played an important role in this system by providing sources of risk, their importance, and their dependency on other risks. The system then gave a range of activity time estimates, the expected performance time for each phase in the project, and the expected overall project performance time as well as the probability for the project duration.

5 Discussion of Systems

The hypertext information system informs the user of the rights and obligations contained in the contract conditions. The main feature of this system is the use of a series of hypertext nodes to guide the user to relevant information contained in various reference documents. In this way existing published knowledge and information on claims can be made readily available without being re-written as a series of hypertext nodes.

The hypertext guide consists of nodes which are arranged hierarchically in two stages. The first stage deals with the contract wording and the second stage describes the various concepts contained in the contract. Both stages give the user a concise overview of a chosen area from which the user can then select a narrower field for more detailed study. In this way the user guides himself through the hierarchy of hypertext nodes, bypassing irrelevant information, until he reaches a point which interests him. Once there, the user is guided to relevant reference material for detailed information.

From a system developer’s point of view, hypertext offers a more
flexible user interface than an expert system shell program. Hypertext is also more suited to the task of providing users with written information than expert systems. Although expert systems can provide users with information, their main function is to assist in decision making.

The selection and estimation of earthmoving equipment are greatly dependent on human knowledge and experience. However, such knowledge may be limited by personal experience in individual organizations and result in inconsistency or inaccuracy in selecting and estimating earthmoving equipment. The nature of earthmoving equipment selection and estimation and the limitation of personal knowledge therefore make a knowledge based expert system an attractive possibility as a decision support system.

Expert systems using artificial intelligence technology are useful to deal with problems in earthmoving equipment and have certain advantages over traditional quantitative approaches. The main advantages of the expert system developed are given below:
1) Clarity of reasoning.
2) Knowledge is systematically stored.
3) Knowledge and data can be well maintained.
4) The knowledge base can be updated.
5) The system can be easily modified and adapted.
6) Sensitivity analyses can be quickly made.

In the schedule risk identification system, the effects of risks are identified and evaluated following an interactive session with the Hypercard information system. The Excel spreadsheet database used for modelling the project uncertainty then gives the variance of the performance time distribution which indicates risk using artificial intelligence technology. The spreadsheet also provides an easy means for sensitivity analyses of different inputs.

6 Conclusions

The applicability and success of a computer based system on a construction project can depend on the size of the project. If the system needs to be tailor made for a small project, and involves extensive modification and development, the cost benefit is unlikely to be worthwhile. The cost of developing a system, particularly the time
consuming elicitation and synthesis of the knowledge can be very considerable. Therefore, if a system is to be developed and used for a decision support system it should be versatile and flexible. Often systems have been developed which do not suit a specific project because they have not been sufficiently versatile or flexible. Rather like scheduling in construction, different systems are appropriate for different projects. One factor might be, for example, the size of a project.

The development of a hypertext system can be time consuming in the sorting and selection of appropriate and relevant text for inclusion in the system.

Spreadsheets are easy to use and can manipulate data well, and can be easily made to be versatile and flexible.

Shell programs certainly help in reducing the time effort put into prototype expert systems but do little to reduce the phenomenal time and effort needed in knowledge elicitation and the actual technical development of the system.

Computer personnel have the time and business inclination to develop and market systems whereas construction personnel in a small/medium sized company simply cannot find enough time to develop systems. This situation can lead to prototype systems being developed which are not very practical. Research groups, such as those found at universities can help in this situation, providing that they liaise with computer and construction personnel.

7 References


The Contractor must complete the Work within the time specified or he may be liable for damages to the Owner. The Contractor is entitled to an extension to the Contract Time for the following three types of delay:

1. Delays caused by the Owner, Consultant, Other Contractor, or anyone employed or engaged by them, that are contrary to the provisions of the Contract Documents. (Sec. 4.1)

2. Delays caused by a stop work order issued by a court or other public authority, provided that it was not due to any fault of the Contractor. (Sec. 4.2)

3. Delays caused by labour disputes, strikes, lockouts, etc., by any cause beyond the control of the Contractor. (Sec. 4.3)

In addition there are other types of delay which may occur:

4. Delays caused by changes in the work.

5. Other delays, i.e., those under the control of the Contractor.

Fig. 1 Hypertext System
What type(s) of operations will you carry out?

Please input the number of operations you will carry out (Max. is 2).

- General bulk excavation (cuttings, etc.)
- Trench filling
- Excavating at face
- Excavating foundations, etc.
- Excavating for foundations
- Excavating slopes
- Trimming slopes
- Fill for slopes
- Excavating trenches
- Clearing pilot roads through mountains and rocky terrain
- Clearing pilot roads through bush and soft ground
- Clearing floor of borrow or quarry pit
- Shallow cutting with wide slopes (V-shaped ditches, etc.)

What is the average haul distance?

- Within 100 metres
- Between 200 metres and 2 kilometres
- Between 100 and 200 metres
- Over 2 kilometres

Fig. 2 Expert System Screens
What is the material to be handled?

- Clay (natural bed)
- Clay (dry)
- Clay (wet)
- Clay and gravel (dry)
- Clay and gravel (wet)
- Rock mixes (75% rock, 25% earth)
- Rock mixes (50% rock, 50% earth)
- Rock mixes (25% rock, 75% earth)
- Earth (dry, raked)
- Earth (wet excavated)
- Earth (loam)
- Gravel (dry)
- Gravel (wet)
- Sand (dry, loose)
- Sand (dry, compacted)
- Sand and gravel (dry)
- Sand and gravel (wet)
- Sand and clay (loose)
- Sand and clay (compacted)
- Snow (dry)
- Snow (wet)
- Too soil
- Others

Screen for Material Type - B3

What is your estimated overall job efficiency?

- 60 (min/hr)
- 50 (min/hr)
- 45 (min/hr)
- 40 (min/hr)

Screen for Overall Job Efficiency - B10

Fig. 3 Expert System Screens
Fig. 4 Structure of the HyperCard Knowledge Base
<table>
<thead>
<tr>
<th>Risk #</th>
<th>Risk Source</th>
<th>Importance</th>
<th>Confidence Level</th>
<th>Independent (I) or Dependent (D) Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>Productivity</td>
<td>High</td>
<td>Medium</td>
<td>I</td>
</tr>
<tr>
<td>31</td>
<td>Engineering centres</td>
<td>Medium</td>
<td>Medium</td>
<td>D</td>
</tr>
<tr>
<td>32</td>
<td>Engineering resource pool</td>
<td>Medium</td>
<td>High</td>
<td>D</td>
</tr>
<tr>
<td>33</td>
<td>Engineering estimate</td>
<td>High</td>
<td>High</td>
<td>D</td>
</tr>
<tr>
<td>34</td>
<td>Material substitution</td>
<td>High</td>
<td>Medium</td>
<td>D</td>
</tr>
<tr>
<td>35</td>
<td>Qualified staff</td>
<td>Medium</td>
<td>Medium</td>
<td>D</td>
</tr>
<tr>
<td>60</td>
<td>Design Errors</td>
<td>High</td>
<td>Low</td>
<td>I</td>
</tr>
<tr>
<td>90</td>
<td>Design Criteria</td>
<td>High</td>
<td>Medium</td>
<td>I</td>
</tr>
<tr>
<td>91</td>
<td>Code changes</td>
<td>Medium</td>
<td>High</td>
<td>D</td>
</tr>
<tr>
<td>92</td>
<td>Site Investigation</td>
<td>High</td>
<td>Low</td>
<td>D</td>
</tr>
<tr>
<td>93</td>
<td>Design Standards</td>
<td>Medium</td>
<td>Medium</td>
<td>D</td>
</tr>
<tr>
<td>94</td>
<td>Technology</td>
<td>High</td>
<td>Medium</td>
<td>D</td>
</tr>
</tbody>
</table>

Figure 5. Sample of Engineering Design Risks
<table>
<thead>
<tr>
<th>Engineering Risks</th>
<th>Importance</th>
<th>Confidence</th>
<th>Activity Time Estimate (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Optimistic</td>
</tr>
<tr>
<td>Productivity</td>
<td>High</td>
<td>Medium</td>
<td>33</td>
</tr>
<tr>
<td>Design Errors</td>
<td>High</td>
<td>Low</td>
<td>36</td>
</tr>
<tr>
<td>Design Criteria</td>
<td>High</td>
<td>Medium</td>
<td>35</td>
</tr>
</tbody>
</table>

Expected performance time of the engineering design phase is 37.8 months

<table>
<thead>
<tr>
<th>Selected project duration (months)</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability project duration (%)</td>
<td>0</td>
<td>1</td>
<td>12</td>
<td>54</td>
<td>91</td>
<td>96</td>
<td>99</td>
<td>100</td>
</tr>
</tbody>
</table>

Expected project performance time is 59.6 months

Figure 6. Sample of spreadsheet modelling schedule risk