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Case Studies in Construction Automation

Etudes de cas dans l'automation des constructions

Fallstudien für die Automation in der Bauindustrie

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SUMMARY
Increasing complexities and highly specialized construction operations necessitate automation in construction industries. The application of knowledge-based decision support and expert systems is particularly timely. Examples of the application of these systems are presented in the area of construction operation quality control, equipment selection, and value engineering.

RESUME
L'augmentation de la complexité et le haut degré de spécialisation des opérations de construction nécessite l'automatisation de l'industrie des constructions. L'application de systèmes de soutien à la décision basés sur la connaissance et de systèmes experts est particulièrement opportune. Des examples d'applications de ces systèmes sont présentés dans le cadre des opérations de contrôle de qualité des constructions, du choix des équipements et de la conservation de la valeur des constructions.

ZUSAMMENFASSUNG
Die zunehmende Komplexität der hochspezialisierten Bauvorgänge erfordert im Bauwesen eine gewisse Automation. Die Anwendung von wissensbasierten Entscheidungshilfen und von Expertensystemen ist angezeigt. Beispiele derartiger Anwendungen auf den Gebieten der Qualitätssicherung, der Geräteauswahl und der Werterhaltung werden beschrieben.

1. INTRODUCTION

Construction expertise is commonly achieved through several years of on-site construction experience. However, rapid technological advances currently characterizing the construction industry do not allow engineers the luxury of slowly acquiring their qualifications on the job. Furthermore, the variety of the constructed facilities, materials, and technologies makes it impossible for one to achieve the expertise in various construction fields during one's lifetime. Some of the expertise is transferred or disseminated to others, while much more is lost.

In addition to this, construction projects are often characterized by many complicating realities, such as: differing cultures, customs and languages; remote sources of materials; shortages of skilled labors; local construction regulations; and large geographical distances between the construction sites and the home office. All of these realities lead to problems which require fast, effective solutions. The problems involved in such construction activities must be solved under the direct pressures of meeting a rigid quality standards and time schedules, budgets, and safety requirements. Managers must accomplish their goals while using limited resources on projects which differ widely from any experienced before.

As a result, adequate substitutions for construction experience are fast becoming a necessity. One promising way to overcome the above problems is through construction automation, such as through the use of knowledge-based decision support or expert systems. These systems fall in the area of the artificial intelligence (AI). Earlier studies related to expert systems have been presented in international conferences. Fuzzy reasoning expert system developed for assessing damage level of protective structures based on the repairability, functionality, and structural integrity criteria was presented in conferences in China [6] and Japan [4]. Another expert system developed for assessing the causes of construction failures in a concrete beam was presented in a Robotic Symposium in Israel [3]. An application of AI to Value Engineering was presented in an International Symposium in Indonesia [1]. This paper evaluates the applications of knowledge-based systems developed by the author for various construction purposes, such as, for construction operation quality control, construction equipment selections, and construction value engineering.

2. CONSTRUCTION OPERATION QUALITY CONTROL

In order to substitute field experience with adequate quality control, one has to recognize the factors which impact the performance of construction operations. These factors are classified into three categories, i.e., factors concerning site activities, factors concerning home office activities, and factors concerning the construction business environment. An expert system developed for this purpose is called the Integrated Management Information System (IMIS). Due to space limitations only factors concerning site activities are discussed here. These factors impacting construction site activities have been identified and defined earlier in another paper [2]. They are cost achievement, construction performance degree, performance of the project manager, administrative efficiency, labor control, material control, equipment control, and site management contingency.

The Cost Achievement (CA) depends upon the Contract Cost (CC), Target Cost (TC), and Actual Cost (AC). The interrelationships of CC, TC, and AC are the subfactors which can be exemplified as follows: If CC is larger than TC and TC is larger than AC, then cost achievement, CA, is very good. The Performance Degree (PD) is identified by the existence of an incentive or dispute or claims. As an example, if the construction project has built in financial incentives from the out set and no dispute arises, then the PD may be considered excellent. The performance of a Project Manager (PM) depends upon his/her competence and balance between authority and responsibility. For instance, a competent project manager whose authority equals his/her responsibility may be rated as very good, while an incompetent project manager whose reponsibility is greater than his/her authority can be rated as extremely poor. The Administrative Efficiency (AE) depends upon the organization and interrelationships among the staff and personnel. For example, an excellent AE can be achieved if a strong organization exists and if the site office is staffed with compatible and efficient personnel.

A construction project requires effective control of resource-related activities such as labor, material, and equipment needed to complete the project efficiently. The Labor Control (LC) is devided into three subfactors: productivity, wage, and working condition. Two subfactors identified within the context of Material Control (MC) are cost and handling of material, while Equipment Control (EC) depends on the productivity and cost. Site Contingency (SC) has frequently been overlooked. Potential contingencies should be identified, and then measured with the lowest possible cost. For example, a highway construction built on a government land in the middle of a farm country in South East Asia required the erection of high livestock type fence along the project. However, soon after the fence was erected, the local farmers whose life line was affected, began to protest and eventually vandalized the fence. A measure was then compromised by erecting pedestrian overcrossing bridges in the affected area. Should such a contingency be identified earlier, adequate measure can be planned at a more adequate time at a reasonable cost.

An expert system shell, 1ST-CLASS [7], was used for developing the production rules using the above factors, subfactors, and their values. Most of the rules use qualitative linguistic values. The shell was designed for IBM personal computers and other compatibles. The forward chaining process was used to infer the rules in the knowledge bases. Further inferencing is performed when a factor is selected. For example, if we are interested in the Cost Achievement (CA), the second line is selected and Figure 1 will appear on the screen showing nine production rules for CA in the form of a decision tree. Essentially, the decision tree shown in this figure is composed of the conventional IF-THEN statements. For example, the first rule (line 1 through 3) in the above may be read as follows:

IF (CC vs TC) leads to (CC is larger than TC)
AND (TC vs AC) leads to (TC is larger than AC)
THEN CA is "Very Good"

In this example, the linguistic value of CA in the THEN statement is "Very Good." The values used in the rules are: Excellent, Very Good, Good, Fairly Good, Fair, Fairly Poor, Poor, Very Poor, Extremely Poor, Undecided/Unknown. The software, IMIS, was developed for integrating information gathered from all factors described previously. This integrated information can be used to assess the performance of a construction project, to compare the performance of several projects, and to make decisions for improving the performance or progress of a project.

3. CONSTRUCTION EQUIPMENT SELECTION

Many factors must be considered in selecting equipment for use in concrete placement during building construction. These factors are based upon experience, judgment, and computational procedures. Factors, such as, equipment working space limitation, operator effectiveness, and equipment versatility are generally assessed based upon experience and judgment. Other factors, such as, equipment capacity and the minimum cost for hiring equipment are generally computed from available information. The use of a concrete operation decision support system (CODSS) is introduced here to help engineers make decisions for obtaining an optimal approach to concrete placement in building components [5]. The CODSS is a preliminary system that can be extended by adding more rules pertinent to the decision making. The expert system shell,"1ST CLASS," is again used for constructing the required knowledge bases.

The knowledge representations consist of four levels as shown in Figure 2. The first level is related to the building components that will be poured, the second level includes the constraints that may exist in the operations, the third level incorporates the selection of equipment, and the fourth level is associated with the computational procedures for finding the duration, cost, and production rate of the selected equipment. The task of placing concrete can be performed through the use of cranes and buckets, concrete pumps, pressure sprays, or conveyor belts. CODSS is limited to the use of mobile cranes, internal cranes, external cranes, and concrete pumps, since they are most likely used for concrete placing in multi-story buildings. The building components generally consist of footings, columns, beams, slabs, and walls. Each of these components may call for different equipment and approaches in concrete operations. Therefore, the choice of the component may result in an individual knowledge base.

Several factors dictate the use of concreting equipment. Five factors that are considered in CODSS are: 1. the specification that may or may not dictate the use of such equipment, 2. the working distance or working line between the crane or pump to the pour location. 3. the availability of working space that may affect the choice of concreting equipment, 4. the versatility and adaptability of the equipment selected, and 5. the operator's effectiveness in operating the equipment. Pumped concrete is usually conveyed by pressures through pipes or flexible hose and discharged directly into the desired area. The types of pumps considered here are: piston pumps, pneumatic pumps, and squeeze pressure pumps. Factors considered for pump selection are the pumping distance, concrete mix slump, and the pipe diameter. The cranes considered in this study are the mobile crane, internal tower crane, and external tower crane. In order to decide which type of cranes are most suitable for use in a project, the following factors should be considered: the building height, the ratio of the length to the width of the building, and specific requirements for an internal crane (e.g., a climbing crane may be called for use in a multi-story building since the mast of the crane can move upward as construction progresses). All cranes are assumed to have the capacity for lifting the bucket containing the concrete mix.

CODSS consists of 11 knowledge bases constructed within an expert system shell. An example of a rule tree (consisting of a set of production rules) for equipment selection based upon the operational constraints is shown in Figure 3. For instance, the third branch from the top of the rule tree can be rewritten as follows:

IF the SPEC. REQ. is optional and
the height of the building is over 600 ft.
THEN infer to CRANE

The consequent (THEN statement) will infer this branch to another rule tree related to CRANE, and so on. CODSS also incorporates 3 external programs written in BASIC that can be called into 1ST CLASS. These programs are used to compute the cost and productivity of the selected pumps and cranes. At this stage, the system is limited to concrete placing only; however, as research progresses, more activities can be accomodated by and integrated into CODSS.

4. VALUE ENGINEERING EXPERT SYSTEM

Value engineering (VE) in construction is a field of study emphasizing functional analysis of construction activities or items through a systematic and organized approach in order to obtain the required functions at minimum costs. Hence, an important part of this approach is the evaluation of the functions, where ideas, judgment, brainstorming, and services from experts are essential for the success of a VE study. In our earlier paper (Hadipriono and Chandra, 1987) the construction of a knowledge base containing production rules for the application of the Functional Analysis System Technique (FAST) was introduced. However, the application of expert systems in a VE study can be extended to the creation, evaluation, and selection of alternatives.

As an example, an item is determined as a <u>steel frame.</u> It is generally conceived that a frame consists of columns and beams. And the functions of the frame is evaluated as (using verb-noun): frame-building, support-loads, or provide-shape. The VE analyst determines which of the three functions is the most important. His/her choice becomes the basic function. The next logical step is to generate ideas that will perform this basic function besides the steel frame. This process is employed to create alternatives for performing the selected basic function. To continue our example, three reasonable alternatives are then created, they are: 1. cast-in-place concrete frame, 2. precast concrete frame, and 3. timber frame. This process of generating, evaluating, and selecting alternatives can be performed through the use of production rules. A user may use the rules by first identifying the desired item, activity, or function. The inference mechanism in the shell will then infer the desired item or function to the rules in the knowledge base. As an example, if the knowledge engineer wishes to relate the functions to the alternatives, then he/she can develop the following rules:

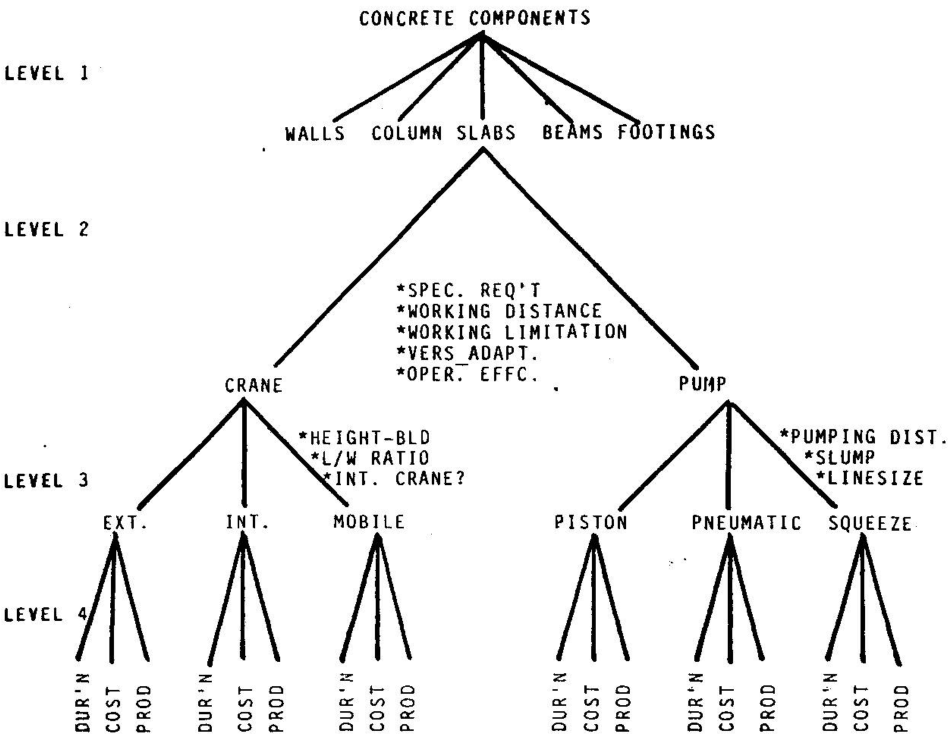
RULE A:
IF function is frame-building
THEN alternatives are:
1. cast-in-place concrete frame (0.25),
2. precast concrete frame (0.25),
3. timber frame (0.25), or
4. steel frame (0.25)

RULE B:
IF function is support-loads
THEN alternatives are:
1. cast-in-place concrete frame (0.3),
2. precast concrete frame (0.3),
3. steel frame (0.3), or
4. timber frame (0.1)

RULE C:
IF function is provide-shape
THEN alternatives are:
1. timber frame (0.4)
2. steel frame (0.3)
3. cast-in-place concrete frame (0.2), or
4. precast concrete frame (0.1)

Note that the figures within the brackets indicate the certainty factors. In this example, these factors determine the rank of the alternatives. In Rule A, these factors indicate that if the function is frame-building, then the alternatives will have the same rank. If the function is support-loads (Rule B), then the choice is equally important for cast-in-place concrete, precast concrete, and steel frames, but least important for timber frame. If the function is provide-shape, then the highest rank of alternative selection is timber frame while the lowest is precast concrete frame. Certainly, these factors could vary, depending upon the characteristics of the project, such as, location, fabrication methods, and erection techniques, and resource availability. For a more refined rules these characteristics are included in the IF statements of the rules. In general, these factors are obtained from the construction experts. For example, the first alternative in Rule C can also be interpreted as: 40% of the experts feel that timber frame is the best alternative for providing the shape of a building. With the help of experts, the knowledge engineer may continue develop and refine the production rules for evaluating each alternatives. The incorporation of menu driven options for assessing these alternatives could result in a powerful and user's friendly system. The engineer can further associate the alternatives with the cost analysis for selecting the best alternative. External programs may be needed for estimating the cost of each alternative before selecting the best one.

```
---- start of rule ----
CC vs.TC??
├CC>TC:TC.vs.AC??
│        ├TC>AC:────────────────────────────────VeryGood
│        ├TC<=AC:CC.vs.AC??
│        │        ├CC>AC:─────────────────────────FairlyPoor
│        │        └CC<=AC:────────────────────────VeryPoor
│        └Und/Unk:────────────────────────────────Und/Unk
├CC<=TC:TC.vs.AC??
│        ├TC>AC:CC.vs.AC??
│        │        ├CC>AC:─────────────────────────Excellent
│        │        └CC<=AC:────────────────────────FairlyGood
│        ├TC<=AC:─────────────────────────────────Extrem.Poor
│        └Und/Unk:────────────────────────────────Und/Unk
└Und/Unk:─────────────────────────────────────────Und/Unk
---- end of rule ----
```




```
---- start of rule ----
SPECI-REQUI??
├crane:──────────────────────────────────#CRANE
├pump:───────────────────────────────────#PUMP
└optional:HEIGHT??
          ├over-600ft:───────────────────#CRANE
          └under-600ft:#WORK-LIM??
                       ├space-avail:VERS-ADAPT??
                       │            ├yes-crane:OPER-EFFC??
                       │            │          ├good(p):───PROBLEM
                       │            │          └good(c):───#CRANE
                       │            └no-crane:OPER-EFFC??
                       │                       ├good(p):───#PUMP
                       │                       └good(c):───#CRANE
                       └no-space:VERS-ADAPT??
                                 ├yes-crane:OPER-EFFC??
                                 │          ├good(p):───PROBLEM
                                 │          └good(c):───#CRANE
                                 └no-crane:───────#PUMP
```

5. CONCLUSION

The emergence of new construction materials and technologies calls for the automation in several construction areas. As part of the construction automation, the knowledge-based decision support and expert systems have only been recently introduced to the construction industry. However, their application is particularly timely. Such systems may take years in the making. As more and more rules are updated and added to the existing knowledge bases, the accuracy and reliability of these systems could increase. They are fast becoming a necessity for an efficient management of construction projects.

REFERENCES

1. Hadipriono, F.C. and Chandra, S., 1987, "Value Engineering Rule-Based Expert System," Symposium of Computer Application in Civil Engineering Education, Indonesia.

2. Hadipriono, F.C. and Chang, K.S., 1988, "Performance Assessment of Construciton Site Operations Using Expert System," Proceedings of the 24th Annual Conference of the Associated Schools of Cosntruction, San Luis Obispo, California, pp 58-67.

3. Hadipriono, F.C. and Lim, C.L., 1987, "Rule-Based Diagnosis of Failure Events," Fourth International Symposium on Robotics and Artificial Intelligence in Building Construction," Haifa, Israel, pp 561-574.

4. Hadipriono, F.C. and Ross, T.J., "Towards a Rule-Based Expert System for Damage Assessment of Protective Structures," Second International Fuzzy Set Association Congress, Tokyo, Japan, pp 156-159.

5. Hadipriono, F.C., Sierakowski, R.L., and Lin, C.S., 1988, "Concrete Operation Decision Support Systems (CODSS)," Fifth International Symposium on Robotics in Construction, Tokyo, Japan, pp 491-499.

6. Ross, T.J. and Hadipriono, F.C., "Fuzzy Production Rules for A Damage Assessment Expert System," Proceedings of the International Sysmposium on Fuzzy Systems and Knowledge Engineering, Guangzhou, China, pp 249-256.

7. Program In Motion (PIM), 1986, 1ST CLASS, Expert System Development Package.