EXPERT SYSTEMS FOR CONSTRUCTION
PROJECT MONITORING

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ABSTRACT: Potential applications of knowledge based expert systems in the area of construction project monitoring and control are described. Originally developed from research in artificial intelligence, these systems are computer programs that can undertake intelligent tasks currently performed by highly skilled people. While some project monitoring can be accomplished by algorithmic procedures, the capability of knowledge based expert systems to deal with ill-structured problems and to be extensively modified over time make them desirable for application in this area. Sample applications and heuristic rules in scheduling and inventory control are provided.

INTRODUCTION

Project Monitoring is one aspect of project management involving checking, regulating and controlling the performance and execution of a construction project. This includes cost control, scheduling and time control, purchasing and inventory control as well as quality control through the entire planning, design and construction process. Project Monitoring is conducted independently or in concert by owner representatives, construction managers, engineers, project managers and others.

Computer aids are available and widely used for many of the activities involved in construction project monitoring (3). However, many of the problems in project monitoring are ill-structured and poorly defined, and thus not amenable to algorithmic approaches. Because the range of algorithmic computer methods is limited, researchers are beginning to investigate heuristic methods to problem solving. "Heuristic" methods include the application of rules of thumb, judgments, and empirical associations in problem solving.

Given the extensive judgment required and the lack of formal structure, project management problems are well-suited to the application of knowledge-based expert systems. Emerging from research in the area of artificial intelligence, expert systems use domain specific knowledge to simulate the reasoning of an expert in the field in order to perform intelligent tasks. Expert systems based on heuristics and empirical knowledge can solve ill-structured problems at or near the performance level of an expert. Some existing applications include computer system design (5), infectious disease diagnosis (9), and identification of ore-bearing formations (1).

This paper is intended to introduce the potential of knowledge based expert systems in construction project monitoring. We provide only a

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brief introduction to expert systems in the next section; more extensive descriptions appear in Refs. 4, 7, and 10. However, our main purpose is to illustrate some possible project monitoring systems including representative knowledge rules and applications. We provide some examples of how expert systems might be structured and usefully applied in the field of construction project management. No production-level expert system currently exists in this area, although small prototypes have been developed (6,11).

**Knowledge-Based Expert Systems**

Knowledge-based expert systems are programs that can undertake intelligent tasks currently performed by highly skilled people. Expert systems use domain specific knowledge and heuristics to perform many of the functions of a human expert. The success of any expert system relies mainly on the ability to formalize and represent the knowledge within a discipline. Often the knowledge is a collection of subjective, incomplete, ill-defined, and informal information. Indeed, a side benefit of expert system development is the formal organization of information that was previously unexpressed.

Ordinary applications programs organize knowledge in data and in the program, with specialized domain specific knowledge implicitly included in the program code. In contrast, expert systems organize knowledge on three levels. Information is contained in data, the knowledge base, and the control procedure. The domain specific knowledge, which is implicit in ordinary programs, is explicitly included as a separate item. A separate specific control procedure exists to manipulate the knowledge. This architecture enables expert systems for different domains to be easily constructed.

There are several components which are common to most expert systems. They are: (1) The knowledge base; (2) the short term memory; (3) the inference engine; (4) the explanation module; and (5) the knowledge acquisition module.

The knowledge base contains general information as well as heuristic or judgmental knowledge. For rule-based systems, this knowledge is represented in the form of IF (condition) THEN (action) rules. Rules may be in the form of situation/action, premise/conclusion or antecedent/consequent relationships. For example:

- **IF:** large concrete pour is scheduled  
  **THEN:** check the capacity of batch plants.

- **IF:** activity has no float time ($TF = 0$)  
  **THEN:** activity is on the critical path.

- **IF:** delivery of material is scheduled to be late.  
  **THEN:** activity will be delayed.

The combination of these rules represents the reasoning of an expert in the field and contains the specific knowledge required to solve problems within the domain of the system.
Because few decisions can be made with certainty, expert systems can be constructed to recognize the uncertainty inherent in decision making. For example,

IF: activity has a cost overrun
and activity is labor intensive
and productivity has been adequate
THEN: the reason for the overrun is probably a poor estimate
of the effort required for the activity
WITH: probability = 0.8.

This permits expert judgments to be represented with realistic probabilities. However, determination of the exact probability of a conclusion based upon a long and complicated string of such rules is difficult. In practice, expert systems use some simplified combinatorial expressions to account for conditional probabilities.

The context or short term memory is often referred to as the fact base. This is a dynamic data base that represents the current state of the system. As the actions of the rules are executed, the facts in the short term memory are changed to reflect these actions. Thus, if the rule

IF: new material is stored in inventory
THEN: inventory level = present amount + new amount.

is executed, the fact base records this by setting the new inventory level to the revised value. In applications in construction project monitoring, the short term memory might include all the data on the status and plan for a particular project gathered during the construction process.

The inference engine or executor is responsible for the execution of the system through manipulation of the rule base and the short term memory. In general, the inference engine selects an “active” rule (one in which the premise is satisfied) and executes or performs the indicated action.

Three types of interrelated components may be used to locate active rules:

1. A Change Monitor detects changes in the short memory that may require attention.
2. A Pattern Matcher compares the short term memory with the knowledge base.
3. A Scheduler decides which action is the most appropriate.

The combination of these various components forms the matching section of the inference engine. From the point of view of the programmer, this is the most difficult aspect. However, because several systems currently exist (8,12), it is possible and more economical to adopt systems with this component rather than to develop a new system from scratch.

Once a rule is selected, two other components are used to perform the required actions:

1. The Processor executes the required actions.
2. The Knowledge Modifier makes changes in the knowledge base as specified by the performed actions.

The inference engine uses a combination of these components to manipulate the rule base and the context in order to locate and execute active rules. Two processing strategies are generally used in existing systems:

1. Antecedent driven or forward chaining (also known as bottom up processing)—System begins with all the required facts and searches to find the best conclusion that fits the facts.
2. Consequent driven or backward chaining (also known as top down processing)—System begins with a hypothesis and works backward checking to see if the facts support the hypothesis.

Forward chaining systems would be appropriate for most of the illustrative systems described below.

Other components that are desired in an expert system are the explanation module and the knowledge acquisition module. In order for the user to have confidence in any conclusion reached by the expert system, it is essential that the system be capable of explaining its reasoning. Thus, the explanation module is a very important part of any expert system.

The explanation module is not necessarily a separate entity. An explanation of the systems' actions is actually contained in the rules that are fired. As a minimum, the explanation module should be capable of repeating the last rule. Then if the user required additional explanation, the module would successively list previous rules which were evaluated.

More advanced systems are capable of supplying more comprehensive answers to a user's questions, such as: (1) How it arrived at a specific decision; (2) why an alternative decision was not reached; (3) how a piece of information was used or why the information was ignored; (4) what decisions were made for the various subproblems; and (5) what are the current actions of the system.

A final component that is desired in an expert system is a knowledge acquisition module. It is not now possible to construct a knowledge base that contains all the knowledge of a specific discipline. As the system is demonstrated and put into practice, experts will contribute additional rules and suggestions to augment the knowledge base. An expert system should be capable of adding rules to the knowledge base in a simple and graceful fashion. Usually it is easy for the programmer or writer of an expert system to add rules to the knowledge base. However, this is extremely difficult for anyone else. Current research is attempting to develop a knowledge acquisition module that allows the expert to build the knowledge base rather than require a computer programmer for assistance.

In contrast to the rule based system described earlier, network based expert systems represent knowledge through a network of nodes and arcs. Two types of network based systems, semantic networks and frame based systems, use different representations to form the knowledge base.

Semantic networks emphasize the relationship between various items. The nodes in a semantic network represent objects, concepts, or situa-
tions with the arcs representing the relations between the nodes. To describe an activity within a project network, the two statements, "The activity is part of the foundation work" and "The activity is preceded by site preparation," may be represented as in Fig. 1.

Frame based systems use nodes and relations to emphasize the objects in a network. Each frame contains a top level node that is constant, and several lower levels containing slots. Slots may be descriptions or relationships such as "made-of," or slots may indicate an action (or series of actions) to be performed, such as how to compute a given value. For example, a frame describing a typical construction activity might be:

```
ACTIVITY
Number: 10-10-02317-390
Name: Excavation for Foundation Pilings
Duration: 30
Estimated Cost: 10,400
EST: 10
LST: 10
Project Number: 435
```

In the preceding example, the node is defined as an "ACTIVITY." The slots (number, name, duration, estimate cost, EST, LST, and project number) are used to define the activity. These slot values may be changed whenever appropriate.

**Potential Role of Expert Systems in Project Monitoring**

A major complaint concerning the available computer systems is that programs are often too limited and rigid for a company's individual needs. Most contractors feel that computers are not capable of making the subjective judgments required throughout the project monitoring process. Computers are considered to be a helpful aid when executing a standard function with a very well defined algorithmic procedure, but are considered incapable of performing the judgmental and higher level aspects of project management. While it is true that computers cannot substitute for or eliminate the need for project managers, they can perform beyond their current algorithmic and accounting functions. Expert systems based on empirical knowledge and heuristics are capable of making subjective judgments in order to perform intelligent functions. In other areas of civil engineering, two expert systems, PROSPECTOR and SACON, have already proven their usefulness as consultants to engineering professionals (10).
The range of applications for expert systems varies from interpretation and derivation at one end of the spectrum to formulation and generation at the other. In general, however, there are several items that characterize the domain of expert systems (2):

1. Algorithmic methods are either not feasible, too cumbersome or too restrictive.
2. There are recognized experts in the field.
3. The task requires from ten minutes to a few days when performed by an expert.
4. The task is primarily cognitive with reasonably high level concepts or objects involved.
5. The task has a substantial payoff.

Many of the functions of project monitoring fulfill these conditions. Expert systems could be used to conserve the scarce resource of a project manager’s time by relieving him of some tasks. For junior or inexperienced personnel, expert systems can play the role of a knowledgeable assistant or checker. In addition, an expert system might ensure that some problems or opportunities are not overlooked. In the future, expert systems could play a significant role in this field. Three areas of project monitoring are exceptionally well suited to the applications of expert systems: cost control, time control, and purchasing and inventory control. Following sections address the development of expert systems within these domains. While some aspects of these systems could use algorithmic procedures, the full scope of the applications would be difficult to achieve outside of a knowledge based framework.

**Cost and Time Control**

Because the cost control and time control aspects of project monitoring are so closely related, it is difficult to separate their individual functions. Thus, an expert system involving either of these two areas will likely include the other.

During the life of a project, cost and time control involve comparison of estimation data, activity schedules and accounting reports. A data base would contain schedules and estimates. For each activity, the following data items might be input each week: (1) Estimated percent complete; (2) expenditures to date; (3) actual quantities of labor (man-hr); (4) actual quantities of material; and (5) actual quantities of equipment (hr). In addition, the following two items are input once for each activity: (1) Actual Start Time (AST); and (2) Actual Finish Time (AFT).

An initial expert system in the area of cost and time control could be established to verify these weekly inputs to the data base. The system would analyze the other information in the data base and based on the rules contained in the system’s knowledge base, determine whether or not the new accounting information is reasonable. If the expert system decided that an input was questionable, it would call this item to the attention of the user and request new input or confirmation of the current value.

A system of this type would automatically be executed whenever new
data is entered into the database. After the weekly accounting information is input, the system would begin analysis of the new data.

When analyzing the actual start time (AST) or the actual finish time (AFT) of an activity, the system would compare the new values with:
1. Previous values of AST or AFT for this activity;
2. Values of AFT for predecessor activities;
3. Scheduled activity times (EST, LST, EFT, LFT);
4. Estimated durations; and
5. Previous and current estimated percent complete.

When verifying values for estimated percent complete and expenditures to date, the system would consider:
1. Previous values of percent complete and cost to date;
2. Activity schedules;
3. Estimated durations;
4. Unit costs and expended quantities for manpower, material and equipment;
5. Estimated cost; and
6. Previous quantities for manpower, material and equipment.

Finally, when comparing actual expended quantities (labor, equipment, and material), the system would use:
1. Estimated quantities;
2. Percent complete;
3. Expenditures to date; and
4. Activity schedules.

A typical rule in the system knowledge base would be of the following form:

IF: percent complete > 0 and AST is not initialized
THEN: one of the two values must be wrong.

A more advanced expert system would be capable of recognizing cost overruns or time slippage problems and diagnosing potential causes. This system would also be executed automatically whenever new accounting data is entered into the database. Based on a predetermined level (say in excess of 15% of the estimate), the system would spot individual activities with cost overruns or time delays. The system would not be limited to completed activities but would also function for activities in progress. In order to determine potential overruns for activities in progress, rules could be established based on the type of activity and comparing the AST, costs to date and percent complete with estimated cost, estimated duration, EST, and LST. Thus, the expert system would provide early warning on potential overruns and time delays before the problem became critical.

The knowledge base for this system would contain many rules concerning activity schedules that would be applicable to all types of activities. Rules would concentrate on comparing estimated data with actual project data. For example:

IF: (percent complete * estimated cost * adjustment value) > (expenditures to date * 1.15)
THEN: when complete, activity will probably have a significant cost overrun.

An adjustment value is added to the equation to account for the normal fluctuations in productivity during an activity. Although the amount of productivity fluctuation varies for each activity type, in general, productivity is lower towards the beginning and end of an activity, as rep-
FIG. 2.—Illustrative Forecast Expenditure Curve

represented by the S curves, which forecast expenditures over the span of an activity. (See Fig. 2.) For example, a project manager may expect the following relationship between percent complete and percent of total cost expended to date:

<table>
<thead>
<tr>
<th>Percent Complete</th>
<th>Expenditures (% of Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>65</td>
<td>60</td>
</tr>
<tr>
<td>85</td>
<td>75</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

To include this knowledge in the expert system, the following adjustment values would then be used:

<table>
<thead>
<tr>
<th>Percent Complete</th>
<th>Adjustment Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>15</td>
<td>((25/15) = 1.67)</td>
</tr>
<tr>
<td>35</td>
<td>((40/35) = 1.14)</td>
</tr>
<tr>
<td>50</td>
<td>((50/50) = 1.0)</td>
</tr>
<tr>
<td>65</td>
<td>((60/65) = 0.92)</td>
</tr>
<tr>
<td>85</td>
<td>((75/85) = 0.88)</td>
</tr>
<tr>
<td>100</td>
<td>1.0</td>
</tr>
</tbody>
</table>

In implementation, these adjustments could be subprograms, which are called by particular rules.

As the system is developed and expanded, additional rules could be added that would be applied to specific activity types. These rules, which represent very specific expert knowledge, are required to enable the system to properly analyze an activity’s status. A typical activity specific rule for defining an activity’s adjustment value might be:
IF: activity is pouring concrete for foundation
and percent complete = 15%
THEN: adjustment value = 1.50.

This activity specific knowledge might also be included in the expert system in a frame representation. A general default adjustment value would be defined. In addition, slots would be available for listing the adjustment values for each activity type based on the percent complete. These slots may contain a single value or an equation for computing the adjustment value. If the slot for the adjustment value is empty for a specific activity, then the system would use the default value as the adjustment value for this activity.

As the size of the system increased, Meta-rules (rules about rules) could be developed to limit the focus of the expert system and minimize the amount of computer time required. For example:

IF: percent complete = 100%
THEN: only consider final values, do not consider rules concerning activities in progress.

However, if the system became too large, it might be necessary to develop separate systems for different activity types in order to limit the size of the knowledge base.

A more creative and useful expert system would incorporate the functions of the two previous systems plus the ability to anticipate future contingencies. Unlike the two previous systems, this system would be more generative than diagnostic. The system would analyze current project data and past trends to previous projects in order to provide insight for the remaining current project activities and future projects. This system would be available as a consultant to a project manager and would be executed at the beginning of a project and again whenever the project manager decides it may be beneficial.

There are several functions that would be included in this advanced system, including:

1. Analyze the proposed project schedule and suggest improvements based on previous experiences and past trends.
2. When the project is partially complete, the system could be requested to update the remaining schedule to reflect progress to date.
3. Predict and anticipate problems that may occur during the course of a project.
4. Suggest remedies for predicted problems.
5. Revise proposed project schedule to allocate resources based on current availability while minimizing overall time and cost (resource leveling).
6. Suggest possible activity duration or cost changes based on past trends.

A typical rule in the knowledge base may be similar to:

IF: activity is on critical path
<table>
<thead>
<tr>
<th>Rule (1)</th>
<th>Description (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>401</td>
<td>IF: schedule has been significantly changed THEN: re-run CPM scheduling program on the remaining activities in the network.</td>
</tr>
<tr>
<td>402</td>
<td>IF: schedule is changed THEN: check material orders and delivery times.</td>
</tr>
<tr>
<td>403</td>
<td>IF: Predecessor Node (PN) of one activity = Termination Node (TN) of another activity THEN: the one activity follows the other.</td>
</tr>
<tr>
<td>405</td>
<td>IF: estimated labor for a project week exceeds 1.25 times the average labor demand for the project THEN: labor demand for the project week is high.</td>
</tr>
<tr>
<td>406</td>
<td>IF: estimated labor for a project week is less than 0.75 times the average labor demand for the project THEN: labor demand for that project week is low.</td>
</tr>
<tr>
<td>407</td>
<td>IF: labor demand for a project week is high and labor demand for the week preceding or following an activity is low THEN: consider re-scheduling the activity to minimize fluctuations in the resource requirements.</td>
</tr>
<tr>
<td>408</td>
<td>IF: EST of activity A &gt; EST of activity B and &lt; EFT of activity B THEN: the two activities are scheduled concurrently.</td>
</tr>
<tr>
<td>409</td>
<td>IF: EST of activity A &gt; EFT of activity B THEN: the two activities are scheduled at separate times.</td>
</tr>
<tr>
<td>410</td>
<td>IF: two large concrete pours are scheduled concurrently THEN: consider separating the activities to level out the amount of labor required and possibly use the same formwork.</td>
</tr>
<tr>
<td>411</td>
<td>IF: several small concrete pours are scheduled at separate times THEN: consider rescheduling the activities at the same time to minimize crew fluctuations and have sufficiently large batches of concrete.</td>
</tr>
<tr>
<td>412</td>
<td>IF: activity number is xx-xxx-03314-xxx and estimated quantity of concrete is greater than 15 C.Y. THEN: activity is a large concrete pour.</td>
</tr>
<tr>
<td>413</td>
<td>IF: activity number is xx-xx-03314-xxx and estimated quantity of concrete is less than 6 C.Y. THEN: activity is a small concrete pour.</td>
</tr>
<tr>
<td>414</td>
<td>IF: activity number is xx-xx-03314-xxx and estimated quantity of concrete is less than 3 C.Y. THEN: activity is a very small concrete pour.</td>
</tr>
<tr>
<td>415</td>
<td>IF: very small (odd) concrete pours THEN: use these activities as fill-ins to keep crews active.</td>
</tr>
<tr>
<td>416</td>
<td>IF: rebar tying (xx-xx-03204-xxx) is not scheduled concurrently with excavation (xx-xx-023160-xxx) or forming (xx-xx-03103-xxx) THEN: change schedule to level iron worker requirements and condense schedule.</td>
</tr>
</tbody>
</table>
and activity is labor intensive
and sufficient labor is available
THEN: it may be possible to shorter activity duration
and reduce overall project time.

In order for the system to evaluate this rule, several other rules may be required, such as:

IF: labor cost is x% of activity cost
THEN: activity is labor intensive.

Thus a highly skilled and experienced project manager is required to develop the intricate network of production rules required for an extensive knowledge base.

Although much more complex than the previous systems, these functions are all within the realm of expert systems. Using the data base outlined previously and project information from past projects, an expert system could be developed to perform any subset of these functions. Some representative rules for these systems appear in Table 1. Of course, specific users would not require the full system outlined here. An expert system to aid owners would not necessarily include components related to detailed field supervision or construction management, for example.

**Purchasing and Inventory Control**

Purchasing and inventory control can have a direct impact on project performance. Improper material or late deliveries can cause cost overruns, time delays, and quality problems. One expert system application in the area of purchasing and inventory control would be an aid to a project manager for determining appropriate inventory levels. The goal of this system would be to minimize overall material cost. To accomplish this task, the system would compare the cost of storing the material in inventory versus the cost of not having the material available when it is required.

If the system decided to maintain a certain level in inventory, then the cost would be the cost of storing the material in inventory until the material is consumed. If the system proposed an inadequate supply in inventory, then the cost would be the cost of storing the material in inventory plus the cost of not having the material available. Thus, the task of the expert system would be to minimize these costs based on the probability of each occurring.

In order for the system to determine an adequate supply level, the amount of time for material consumption and the probability of material unavailability, several other factors need to be considered including: (1) Frequency of use; (2) comparison costs; (3) amount used per period; (4) delivery time; (5) whether or not the item is readily available; and (6) past project data.

Through a series of rules concerning this information, a knowledge base could be constructed which would enable an expert system to make judgments concerning appropriate inventory levels. An extension would
Table 2—Some Representative Purchasing and Inventory Control Rules

<table>
<thead>
<tr>
<th>Rule (1)</th>
<th>Description (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>501</td>
<td>IF: material is concrete THEN: average delivery time is 3 days.</td>
</tr>
<tr>
<td>502</td>
<td>IF: material is reinforcing bar THEN: average delivery time is 3 weeks.</td>
</tr>
<tr>
<td>503</td>
<td>IF: material is anchor bolts THEN: average delivery time is 4 weeks.</td>
</tr>
<tr>
<td>504</td>
<td>IF: material is formwork THEN: average delivery time is 2 weeks.</td>
</tr>
<tr>
<td>505</td>
<td>IF: average delivery time is defined (i.e., 3 weeks) THEN: time period to be considered is twice the average delivery time (i.e., 6 weeks) Consider only those activities occurring within this time period.</td>
</tr>
<tr>
<td>506</td>
<td>IF: inventory levels are not sufficient to last the defined time period (amount in inventory &lt; amount required) THEN: request user to issue change order.</td>
</tr>
<tr>
<td>507</td>
<td>IF: (amount ordered through purchase orders + inventory level) &lt; estimated quantity required during time period for all activities THEN: request user to issue change order.</td>
</tr>
<tr>
<td>508</td>
<td>IF: date of scheduled delivery &gt; date material is required THEN: request earlier delivery of material or check for possible alternative suppliers.</td>
</tr>
<tr>
<td>509</td>
<td>IF: material is not yet ordered and activity is scheduled to begin within the defined time period. THEN: suggest user issue a purchase order for the material.</td>
</tr>
<tr>
<td>510</td>
<td>IF: very large concrete pour is scheduled THEN: suggest the user verify —sufficient capacity of batch plants —sufficient number of delivery trucks —condition of delivery trucks —time to and from the batch plants —manpower availability.</td>
</tr>
<tr>
<td>511</td>
<td>IF: activity number is xx-xx-03314-xxx and estimated quantity of concrete is greater than 30 C.Y. THEN: activity is a very large concrete pour.</td>
</tr>
</tbody>
</table>

be to suggest dates for ordering material. Table 2 contains some representative rules for such a system.

Example of User Consultation

Prior to execution of the project monitoring expert system described earlier, the project network would be run through a CPM or similar project scheduling program. If the project is partially complete, the incomplete and remaining activities would be submitted to the scheduling program. The durations on the partially completed activities would be changed to reflect progress to date. Once a new project schedule has been obtained and entered into the data base, the expert system would then be executed.

The system first considers possible scheduling improvements. Rules that apply to all activity types are considered before the activity specific rules. When performing activity specific rules, the system reads the ac-

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**TABLE 3.—Sample User Consultation**

Enter project name—

??? LANGDON SPECIALTY STEEL PLANT

Is this session for scheduling or ordering improvements?

??? SCHEDULING

Processing Langdon Specialty Steel Plant...

Labor required during Week 9 is very high. Suggest delaying the start of Activity Number 12-13-02317-030 “Excavate pits 7 ft deep” until Week 10.

??? WHY?

During Week 9, the following activities require general labor:

12-13-02317-030
12-32-02310-160
12-11-02110-015

Delaying will not delay overall project completion time and will level labor requirement.

???

Activity Number 01-12-03204-025 “Transport to site and prepare rebar” could be scheduled during same time period as Activity Number 12-13-02316-050 or 01-12-03103-052.

??? WHY?

There is no conflict between activities.
Reduces completion time for foundation.
Ironworker requirement is low during those time periods.

???

Finished processing Langdon Specialty Plant.
Do you wish to analyze any other projects?

??? NO

Please make appropriate schedule changes.
Processing complete.

Enter project name—

??? LANGDON SPECIALTY STEEL PLANT

Is this session for scheduling or ordering improvements?

??? ORDERING

Processing Langdon Specialty Steel Plant...

Material for Activity Number 1-12-03204-025 “Transport to site and prepare rebar” is scheduled for delivery on 8/26/82. The activity is scheduled to begin on 8/12/82. Request an earlier delivery.

???

Purchase order number 1-8147 is not sufficient to meet the needs of the activity. Request a minimum of 8 Cu. Yds. of additional material.

???

Suggest ordering material for Activity Number 01-12-03302-025 “Place 18” anchor bolts

??? WHY?

Material has not yet been ordered and activity is scheduled to begin on 7/30/82.

??? WHY IS THIS IMPORTANT?

Previous suppliers of similar material required an average of 4 weeks for delivery.

??? ARE THERE ANY ALTERNATE MATERIALS?

None that were used previously.

???

Finished processing Langdon Specialty Steel Plant.
Do you wish to analyze any other projects?

??? NO

Please make appropriate ordering changes.
Processing complete.
tivity number from the data base, classifies the type of activity and then "fires" the appropriate set of rules.

Because of their effect on other activities, activities involving large amount of time or money are considered first. While the system is processing the entire project, the context or short term memory records possible schedule changes. As activities are analyzed, the short term memory is constantly updated and revised to reflect the most recent changes.

Once the entire project has been analyzed, the system suggests possible scheduling improvements to the user. The user notes these suggestions and, if acceptable, makes the appropriate program to evaluate the impact of these changes on the total project and obtain a new activity schedule.

The revised project schedule is then analyzed for possible inventory or ordering improvements. Purchase orders and inventory levels are checked for compatibility with the new project schedule. The system notes any problems and suggests ordering changes to the user.

The transaction shown in Table 3 demonstrates both the scheduling and ordering aspects of a project monitoring expert system. The session begins with the user identifying the project name and the requested function. The system then suggests several possible improvements and explains its reasoning. User responses are italicized.

Once a new activity schedule has been determined, the user requests the system be re-executed to check for ordering improvements. Again, the system offers suggestions and provides answers to the user's questions.

IMPLEMENTATION OF KNOWLEDGE BASED EXPERT SYSTEMS FOR PROJECT MONITORING

The preceding sections described some possible application areas for knowledge based expert systems in construction project monitoring. In essence, these systems could be used as aids, advisors and supplemental reviewers to project managers. As the systems were extended and as experience accumulated, the systems could be relied on to an increasing extent as independent monitors. Different systems could evolve to aid different users (owner representatives, contractors, etc.) and different project types.

This emphasis on system evolution in considering implementation illustrates a major benefit of expert systems relative to traditional computer programs. Expert systems can be readily modified and expanded as conditions require. This is possible in large part because of the separation of domain specific knowledge and rules in the "knowledge base" system component and the provision of a mechanism for adding new rules. As a result, expert systems are much easier to modify and maintain than are traditional, algorithmic programs.

The resources required to develop and implement expert systems are in a state of rapid change. Expert systems can now be readily implemented on personal computer workstations, and the costs of the necessary hardware are continually declining. Similarly, software environments to provide a framework for expert system development are
dropping in price and becoming increasingly accessible to nonspecialists.

**CONCLUSIONS**

After the development of large project management data bases and related software, the application of knowledge-based expert systems is a desirable extension. These systems can deal with the ill-structured problems common in this area. They also have the potential for incremental development as users' experience accumulates and is incorporated in additional rules.

An expert system similar to the type presented in this paper should not be considered only as an experiment for a researcher or as having potential future applications. Instead, an expert system in the field on construction project monitoring could be developed for practical use. While the formation of this expert system may require a substantial investment, particularly if the system would have to access an existing data base, this cost could be justified through the benefits of the system.

**APPENDIX.—REFERENCES**