專家系統在土木及農工營建企劃案之監視管理

Knowledge Based Expert Systems in Civil and Agricultural Construction Project Monitoring

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摘　　要

企劃案的監管 (Project Monitoring) 是企劃案管理 (Project Management) 的一個重要面。在這論文裡我們定義 Project Monitoring 包括一個營建企劃案規劃、設計、執行過程中之查驗、規格化與執行管制。也就是包括成本控制、工作排程、時間管制、物料購買、倉貯控制和品質管制。

電腦可以幫助許多Project Monitoring 的工作，但是其中一些問題仍未被恰當的定義也無適當的電腦程式可幫助，因此研究人員試着發現啓發性的邏輯演繹程式來解決問題。

專家系統是電腦人工智慧的一支，其應用啓發性 (Heuristics) 的，特定範圍性的知識和專家判斷去解決困難的問題，藉着模擬專家的分析理由，知識庫專家系統能像專家一樣的執行解決問題。(如電腦圍棋、象棋等)

這論文探討專家系統在營建企劃案之監視管理，首先本文先討論一個正式Project Monitoring的方法，接着看看在這行業裏專家系統可能的應用。兩個可能的應用系統被詳細的討論：

1.一個簡單的會計輸入資料證明系統。

2.一個較複雜的工作排程和次序改進建議系統。

爲了說明這些系統的操作，本文也展示了兩個系統的例樣規則 (Sampl Rule) 與例樣顧問建議 (Sample Consultation)。

ABSTRACT

Expert systems are a branch of Artificial Intelligence that use heuristics, domain-specific knowledge and expert judgements to solve difficult problems. By simulating the reasoning of an expert in the field, knowledge based expert systems are capable of performing at or near the level of an expert.

This paper investigates the application of expert systems in the area of civil and agricultural construction project monitoring. A formal approach to project monitoring is first discussed followed by a review of potential applications of expert systems within the field. Two applications are discussed in detail: (1) A system for verification of weekly accounting input data, and (2) a more complex system capable of suggesting scheduling and ordering improvements. To illustrate the operation of these systems smaple rules and sample consultations for the two systems are presented.

1. Introduction

1.1. Overview

Project Management for civil and agricultural construction stresses the importance of treating the entire sequence of planning, designing, building and occupancy as a whole. Feasibility studies, planning, scheduling, designing, cost control, contracting and management activities are viewed as inter-related elements of the complete, overall system. Allowing for interaction between the various functions eliminates the cost and time penalties inherent in the standard, fragmented civil and agricultural construction process.

A key element in the project management concept is the Project Manager. In general, it is his responsibility to insure the project is completed on time and within budget. There are many features involved in providing this service:

* extensive scheduling and planning
* strict cost control
* access to timely, accurate information
* responsive decision making
* maintaining communication and functioning as a liaison between the owner, contractors, designers, architects and other interested parties.

Civil and Agricultural Project Monitoring is one aspect of project management. For the purpose of this paper, project monitoring is defined as the range of activities involved in 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.

Expert or knowledge based systems are a branch of artificial intelligence which use domain spcific knowledge and heuristics to perform difficult tasks. By representing the reasoning of an expert in the field, expert systems are capable of performing many of the functions of a human expert. Knowledge based expert systems are applicable to the field of project monitoring where knowledge is largely empirical and heuristic and good performance requires the experience of an expert.

1.2. Current Practice of Civil and Agricultural Project Monitoring

The current practice of civil and agricultural project monitoring is often limited to field inspections and subjective judgements. Most project managers rely on their experience and familiarity with a project to monitor the project status. Their knowledge of a project is mainly based on their personal communications and field inspections rather than detailed reports.

A more formal approach to project monitoring involves comparison of accounting and cost reports with activity schedules and previous estimates and expectations. Generally, data is collected in the field concerning estimated percent complete and expenditures to date for each activity. This information is combined and tabulated into formal reports which can then be compared with detailed activitiy schedules, estimated quantities and estimated expenditures. Based on this information, the project manager is able to determine the status of a project.

While this may appear to be a simple process, it is actually extremely complex. This can be demonstrated by analyzing the details involved in: (1) cost control, (2) scheduling and time control and (3) purchasing and inventory control aspects of civil and agricultural project monitoring. It is important to remember these are not three distinct, separate functions, but are closely related with the performance in any one category affecting the others.

Once a project has commenced information must be obtained from the field to gauge the performance of the project and its separate activities.

In order to track and record information for all the numerous activities in an efficient and organized manner, it is essential that a standard, uniform activity numbering system be established.

1.3. Available Computer Aids

From the above description of project management activities, it is obvious that many functions are amenable to computerization. With the recent advances in technology, including the emergence of minicomputers and decreasing capital costs of computer hardware the use of computers is becoming commonplace. The following is a brief summary of the more commonly available aids.

Scheduling and Resource Allocation

Two of the best known and most widely used computer applications in the construction industry are the **Critical Path Method (CPM)** and **Program Evaluation and Review Technique (PERT)** programs. These two network scheduling and resource allocation algorithms use critical path methods to determine an activity schedule and resource allocation for a project. These programs are as easily applied to other types of projects (software development, surgery, maintenance schedules etc.) as they are to construction projects.

Accounting and Reporting

Automated accounting systems are also common throughout the construction industry. Currently availble systems are generally limited to filing data, summing inputs and generating reports. While virtually all information is manually input into the system, the tedious, routine and time consuming tasks of data storage, retrieval and manipulation are eliminated.

Estimating

Computer based estimating is a natural extension of computer aided accounting. Available estimating systems are most helpful after the takeoff stage of estimating. Unit costs are developed by the estimator based on past projects and current market prices and stored in the computer in a data base. The system matches the previously stored unit cost to the items identified by the estimator to determine an estimate for the project. The speed and accuracy of the computer allow the estimator to concentrate more on the subjective aspects of estimating by eliminating his reponsibility to perform the clerical and arithmetic functions.

Purchasing and Inventory

Computer applications in the field of purchasing and inventory control are mainly limited to management information systems. All material in inventory is recorded and stored in the computer in a data base. This information provides accurate and convenient, access to inventory records enabling personnel to quickly determine the amount of a specific material in inventory, where it is stored, when it was purchased, its intended use or any other special factors.

Other Computer Aids

The use of recent development, data base management systems (DBMS) has also aided the construction industry. Advanced systems permit the user to access information without requiring the user to understand the organization and details of the data base.

1.4. Expert Sytem

Introduction to Expert Systems

The currently available computer aids for project management have several items in common:

* All require very structured input and problem formulation.
* Calculation Procedures are algorithmic with very well defined steps.
* Solutions are treated with certainty.
* Solutions and data require professional judgement and expertise to analyze and interpret results, provide insight and determine appropriate actions.

In Practice, however, not all problems and answers can be treated with certainty. Many problem require judgements based on experience to generate potential solutions. Also, the typical algorithmic approach is not easily applied to the complex, nonuniform and ill-structured situations involved in construction. In the past, problems such as these were solved by an expert in the field. Using his knowledge and experience, an expert could solve problems which may appear impossible to a novice.

These problems are well suited to the application of expert systems. As a branch 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 system based on heuristics and empirical knowledge can solve ill-structured problems at or near the performance level of an expert.

This description applies to many of the tasks involved in civil/agricultural project monitoring. Due to the significant benefits which may be achieved, the application of expert systems to the field of civil/agricultural project monitoring deserves investigation.

Rule-Based Systems

There are several components which are common to most rule-based expert systems. There are:

* the knowledge base,
* the short term memory,
* the inference engine,
* the explanation module, and
* the knowledge acquisition module.

The **knowledge base** contains general information and heuristic or judgemental knowledge. This knowledge is represented in the form of If <condition> Then <action> with <certainty> 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 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

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

The **inference engine or executor** is responsible for the execution of the system through manipulattion of the rule base and the short term memory. In general, the inference engine selects and "active" rule 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 term memory which 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.

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.

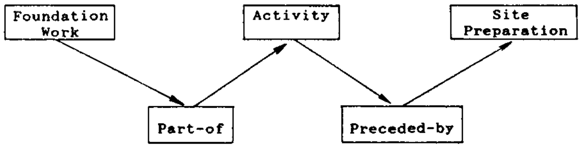
1. Antecedent driven or forward chaining (also known as bottom up processing) – System begins with all the required facts and searches to find the best conclusion that fit the facts.
2. Consequent driven or backward chaining (also known as top down processing) – System begins with a hypothesis and works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

Other components which are desired in an expert system are the Explanation Module and the Knowledge Acquisition Module.

Network Based Systems

Network based expert system, while similar to rule based systems, represent knowledge through a network of nodes and arcs. Two types of network baed system, **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 situations 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:



Frame based system use nodes and relations to emphasize the objects in a network. Each frame contains a top level node which 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. The following is a frame describing a typical construction activity:

ACTIVITY
- Number: 01-10-02317-390
- Name: Excavation for Foundation Pilings
- Duration: 30
- Estimated Cost: 400,000
- EST: 10
- LST: 10
- Project Number: 435

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

Expert System And Its Languages

A number of successful expert systems have been developed over the past decade. The following are most widely known expert systems:

1. MYCIN [MYCIN] was develoed at Stanford University to aid physicians in the diagnosis of bacterial infections and the selection of antibiotics.
2. DENDRAL [DENDRAL] has achieved acceptance and routine use in assisting chemists in the identification of the molecular structure of unknown compounds.
3. PROSP [PROSP], This system uses a combination of rule based and network based system to aid geologists in the evaluation of possible ore deposits at a given site.
4. R1 [R1], The system determines the physical layout and interconnections of the various components, adds support components which may be missing from the order and provides technicians with detailed assembly information.
5. EMYCIN [EMYCIN] is a domain independent system that aids in constructing knowledge based consultation programs. EMYCIN is based on routines originally developed for MYCIN without its domain specific knowledge base.

By far, the most widely used Artificial Intelligence Language is **LISP** (List Processing Language) [LISP]. Unlike other computer languages, LISP uses symbolic expressions and symbol manipulation to form lists. Through the evaluation of these lists, LISP performs it functions.

To illustrate the LISP format, consider the following rule:

IF:
- percent complete > 0
- and percent complete < 100

and Actual Start Time exists (AST > 0)
and Actual Finish Time does not exist (AFT = 0)

THEN:
activity is in progress.

This rule can be represented in LISP form as:

```
(RULE IDENTIFY12
    (IF (GREATERP PERCENT 0)
        (LESSP PERCENT 100)
        (NOT (ZEROP AST))
        (ZEROP AFT))
    (THEN (ACTIVITY-IS
            IN-PROGRESS)))
```

Many variations of AI languages exist, including QLISP, INTERLISP, MACLISP, OPS and so on.

2. Potential Role of Expert Systems in Civil and Agricultural Project Monitoring

2.1. The Domain of Expert Systems

Expert systems based on empirical knowledge and heuristics are capable of making subjective judgements in order to perform intelligent functions. In other areas of Civil and Agricultural Engineering Two expert systems, PROSPECTOR and SACON, have already proven their usefulness as consultants to engineering professionals. In general, however, there are several items which characterize the domain of expert systems [FENV]:

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.

2.2 Project Monitoring Data Base and Activity Code Number

Project Monitoring Data Base

A typical project monitoring data base might contain the following.

Project Monitoring Data Base

Project Information:
The following information is used to describe a construction project.
* Project Number
* Project Name
* Total Project Cost
* Project Start Date
* Number of Activities
* Location
* Owner

Estimating Information:
The following price information is stored to provide the estimator with quick reference to cost data.
* Unit Costs for Labor
* Unit Costs for Equipment
* Unit Costs for Material

Activity Scheduling Information:
After an estimate has been completed and a project schedule has been determined, the following information is stored for each activity.
* Activity Code Number
* Project Number
* Description
* Estimated Duration
* Estimated Cost
* Predecessor Node (PN)
* Termination Node (TN)
* Early Start Time (EST)
* Late Start Time (LST)
* Total Float (TF)
* Free Float (FF)
* Estimated Quantities of Labor, Material and Equipment

Accounting Field Information:
Through the collection of time cards and

equipment requisitions, the following information is tabulated each week and used to generate the Accounting Activity Information and the Accounting Payroll Information.

Time Cards:
  * Employee Number
  * Activity Number
  * Hours worked (divided into activity number categories)

Equipment Requisitions:
  * Equipment Type
  * Activity Number
  * Hours Worked (divided into activity number categories)
  * Hourly Charge Rate
  * Date of Information

Accounting Activity Information:
After construction of the project has commenced, the following data is input each week for each activity.
  * Activity Number
  * Date of Information
  * Estimated Percent Complete
  * Expenditures to Date
  * Actual Quantities of Labor, Material and Equipment (used during this week)

In addition, the following two items are entered once for each activity.
  * Actual Start Time (AST)
  * Actual Finish Time (AFT)

Accounting Payroll Information:
This following information is stored for each employee.
  * Employee Number
  * Employee Name
  * Job Description
  * Hourly Pay Rate

In addition the following two items are generated each week through the accounting system for each employee.
  * Date
  * Hours Worked

Purchase Order Information:
Each purchase order contains the following information.
  * Purchase Order Number
  * Supplier's Name
  * Supplier's Address
  * Type of Material
  * Date Ordered
  * Date Required
  * Date of Scheduled Delivery
  * Amount Ordered
  * Project Number
  * Activity Number
  * Cost of Material

Inventory Information:
The following data is used to describe the material stored in inventory.
  * Type of Material
  * Amount in Inventory
  * Storage Location

This data base is created through the various departments and functions of a construction project management team. Figure 2-1 demonstrates the interaction of this data base with the project management functions. Table 2-1 show a example file containing project information. All departments have access to all aspects of the data base but each can alter only those items which are specific to its function.

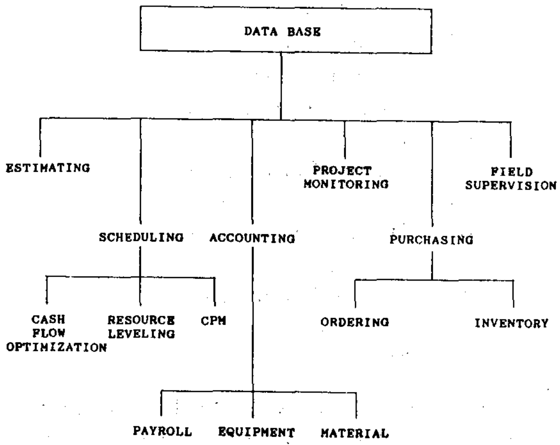


Figure 2-1: Project Management Organization

Table 2-1 : A Example File Containing Project Information

Activity Number	01-11-03314-010	
Actual Start Time	May 3, 1989	
Actual Finish Time	0	
Project Number	105	
Project Name	Mellon Earth Dam	
Owner	Kaohsiung	
Location	Mellon, Kaohsiung, Taiwan	
Total Project Cost	$290,000,000	
Project Start Date	May 3, 1989	
Number of Activities	540	
	Week 1	Week 2
Percent Complete	10%	18%
Expenditures to Date	4322	8290
Labor Hours	84	320
Material Consumption	0	400
Equipment Hours	0	0

Activity Code Numbers

For demonstration purposes, the activities included in this paper as illustrations are identified with a modified activity coding system based on the Uniform Construction Index (UCI) and Means Cost Data [MEANS]: All activities are initially divided into 12 general activity groups (identified by the first two digits of an activity Number). These include:

01 Foundation
02 Substructure
03 Superstructure
04 Exterior Construction
05 Roofing
06 Interior Construction
07 Conveying Systems
08 Domestic Water Systems
09 Electrical
10 General Conditions
11 Equipment
12 Sitework

These groups are each divided into several activity subgroups (identified by the second two digits of an activity number). The final eight digits of an activity code number define the specific activity type and function.

For example, the activity represented by the activity number 01-10-03314-390 can be divided as follows:

01 Foundation
10 Standard Foundation
03 Concrete
3 Cast in Place Concrete
14 Concrete in Place
390 Footings, Strip 18" x 9", Plain

Analysis of this activity number reveals that the activity is a concrete pour for a standard foundation for a 18" x 9" footing requiring no reinforcement. Similar analysis can be performed on all activity number to describe the individual aspects of each activity.

2.3. 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 include the other.

During the life of a project, cost and time control involves comparison of estimation data, activity schedules and accounting reports. The data base described in the previous section contains the information generated through these systems. Included in the data base are several items which are commonly generated weekly through the accounting system.

2.4. 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.

3. An Expert System for Verifying Accounting Data

3.1. Introduction

This section details a specific application of expert systems in the field of project monitoring. The section presents the functions, benefits, requirements and limitations of a system for verification of accounting input data, capable of detecting cost overruns and time delays. Sample rules and a sample transaction are also provided to demonstrate the actual operation of the system. The sample rules that are presented are not intended to be a complete system, but are provided solely for demonstration purposes.

As state earlier, several domain independent expert ystems, such as EMYCIN, have been developed that allow a knowledge engineer to construct an expert system without designing the entire system. It is possible to incorporate a rule base and a network strategy into an existing system and take advantage of the inference engine, knowledge acquisition system and explanation module which already exist. For this reason, the applications that are presented concentrate on developing the rules and network which form the knowledge base.

The two example systems that are proposed in the section and the following section are presented as rule based expert systems. These systems could also be implemented as network based systems or as a combination of the two types. In practice, before either system is constructed, a detailed analysis of the advantages and disadvantages of both types with respect to the proposed application is required to ensure the most efficient use of system capabilities.

Both of the proposed applications operate on the project information contained in the data base which was presented in section 2.2. Any additional information required by either system is contained in the knowledge base or is supplied by the user.

3.2. System Function

The primary function of this expert system is to verify the correctness of the project data supplied by the accounting department. This data may be entered as raw data or may be generated through the accounting system. After the accounting information is determined to be corrrect, the system then attempts to detect and identify potential cost overruns (or savings) and time delays (or savings). Once a problem has been detected, the explanation module provides information concerning the source of the problem and thus it possible causes.

The explanation module for this system would be direct and simple. When the user is uncertain of a specific conclusion reached by the expert system, the user would ask "WHY?". The system would then respond with the last rule which was fired. If this did not provide an adequate explanation, the user could request additional information and the system would recursively repeat the rules in reverse order.

This expert system would be executed each week after the new accounting data is entered into the data base. The system would verify the following information for each activity:

* Estimated Percent Complete
* Expenditures to Date
* Actual Start Time (AST)
* Actual Finish Time (AFT)
* Actual Quantities of Labor (man-hours)
* Actual Quantities of Material
* Actual Quantities of Equipment (hours)

This information is obtained through the collection and tabulation of time cards, equipment requisitions, purchase orders and the field engineers' estimates. These reports are manually collected and entered into the accounting system in order to generate both the accounting activity information and the accounting payroll information. An expert system for verification of accounting activity information would have access to the raw data, as collected in the field and entered into the system, as well as the payroll reports. In addition to analyzing the activity information for correctness, the system would also corss-check this information with the raw data and the payroll reports.

A clerk from the accounting department, who is familiar with the specific project, would execute this system and remain available to note any problems or correct and errors detected by the system. Actual execution of the system would be relatively quick depending on the size of the project and the amount of new information. Also, because the information is already being entered into the data base, the additional cost of executing the expert system would be small.

Existing data base management systems (DBMS) already have the capability of enforcing constraints on data entries. Usually, the constraints on the data are limited to the ability to specify ranges for the data items. For example, a data base manager may specify that any value entered into the data base for Percent Complete must be between 0 and 100%.

Because the constraints that are permitted in the existing DBMSs are very limited and direct, it is extremely difficult to represent the expert judgements that are possible with an expert system. Expert system rules which analyze the project network and make decisions based on the relationships between data items are far more suitable for the complex nature of verifying construction project data. Thus, while a DBMS is very capable of checking and verifying the ranges, bounds and obvious errors of accounting data, they are not designed to perform with the same capabilities of an expert system.

3.3. Benefits

There are several benefits of an expert system of this type.

* The first and most obvious is that most errors in the accounting information can be eliminated. This gives the project manager and other personnel more confidence in the basic data.
* Having the computer verify the data eliminates the need for manual verification and checking.
* Because the system is run immediately after new data is input, new accounting reports do not have to be printed if errors are detected. This decreases the amount of time between data collection and report generation thus making the data more current.
* Computers are able to process a large amount of information very quickly and thoroughly. This eliminates any human error and provides for quick turnaround.
* This expert system provides for early detection of cost overruns and time delays. This eliminates the need for the project manager to perform this function and quickly calls problem areas to his attention. The explanation module may also supply clues to the project manager as to what the problem may be.

Much of the knowledge base of this system can be represented through algorithmic procedures. However, some items require judgements in order to properly evaluate their status. For example, if there is a large increase in percent complete from one period to the next, several other items must be checked in order to properly decide whether or not the input is correct.

Much of work is currently performed by the project manager or an engineer. It their duty to study the project information in order to detect potential problems before they become critical problems. Because this requires the experience and knowledge of an expert, it is potentially within the realm of application for an expert system.

3.4. Sample Rules

3.4.1. Sample Rules For Verifying Data Reasonableness

The system begins by testing the most obvious cases of invalid input. For each activity with updated accounting information, the system applies the following rules to the new data items. If any of the rules are true, the system requests new data. The corrected value is verified by the system before it is entered into the data base.

RULE 001

IF:

percent complete < 0

THEN:

request user to input new value for percent complete.

RULE 002

IF:

percent complete > 100

THEN:

request user to input new value for percent complete.

RULE 003

IF:

Actual Start Time (AST) > accounting date

THEN:

request user to input new value for AST.

RULE 004

IF:

Actual Finish Time (AFT) > accounting date

THEN:

requesting user to input new value for AFT.

RULE 005

IF:

AST < project start date

THEN:

request user to input new value for AST.

RULE 006

IF:

AFT < project start date

THEN:

request user to input new value for AFT.

RULE 007

IF:

AST > AFT

THEN:

request user to verify current value or input new value for AST and AFT.

RULE 008

IF:

accounting date > computer calendar date

THEN:

request user to input new value for accounting date.

RULE 009

IF:

present accounting date < previous accounting date

THEN:

request user to input new value for present accounting date.

RULE 010

IF:

cost to date < 0

THEN:

request user to input new value for cost to date.

The expert system also investigates the more subtle cases of invalid input. When a possible error is noted, the user has the option of replacing a piece of data or confirming the current value.

RULE 101

IF:

AFT exists (not equal to 0) and percent complete < 100

THEN:

request user to verify current values or input new values for AFT and percent complete.

RULE 102

IF:

percent complete = 100 and AFT does not exist

THEN:

request user to verify current values or input new values for AFT and percent complete.

RULE 103

IF:

present percent complete < previous percent complete

THEN:

request user to verify current values or input new values for previous and present percent complete.

RULE 104

IF:

present cost to date < previous cost to date

THEN:

request user to verify current values or input new values for previous and present cost to date.

3.4.2. Sample Rules For Detecting Cost Variances

Once the system determines that all data is reasonable, it then checks for potential cost overruns (or savings) and time slippage (or savings). Again, this is done by first testing the most obvious cases and then the more subtle examples. Because the main concern is overall project cost and completion time, care must be taken to consider the impact of individual activities on the overall project schedule.

RULE 201

IF:

activity is complete

THEN:

check completed costs.

RULE 202

IF:

completed cost > estimated cost

THEN:

activity has an overrun that is equal to (completed cost – estimated cost).

RULE 203

IF:

completed cost < estimated cost

THEN:

activity has an overrun that is equal to (estimated cost – completed cost).

RULE 204

IF:

(percent complete * estimated cost * adjustment value) > (cost to date * 1.15)

THEN:

when complete, activity will probably have an underrun.

RUN 205

IF:

(percent complete * estimated cost * adjustment value) < (cost to date * 0.85)

THEN:

when complete, activity will probably have an overrun.

RULE 206

IF:

activity is Excavation
(Activity number = xx-xx-02316-xxx, xx-xx-02317-xxx or xx-xx-02318-xxx)

THEN:

adjustment value	percent complete
1.6	0 – 15
1.3	15 – 40
1.1	40 – 70
0.85	70 – 90
0.9	90 – 100
1.0	100

RULE 207

IF:

activity is Concrete Pour
(Activity number = xx-xx-03314-xxx)

THEN:

adjustment value	percent complete
1.65	0 – 15
1.4	15 – 40
1.2	40 – 70
1.0	70 – 90
0.95	90 – 100
1.0	100

RULE 208

IF:

activity is Procure Materials for Forwork
(Activity number = xx-xx-03101-xxx, xx-xx-03102-xxx or xx-xx-03201-xxx)

THEN:

adjustment value = 1.0 for all levels of percent complete.

RULE 209

IF:

activity is Backfill
(Activity number = xx-xx-02303-xxx)

THEN:

adjustment value	percent complete
1.6	0 – 15
1.3	15 – 40
1.1	40 – 70
0.9	70 – 90
0.9	90 – 100
1.0	100

RULE 210

IF:

activity is Prepare and Place Rebar
(Activity number = xx-xx-03204-xxx)

THEN:

adjustment value	percent complete
1.2	0 – 15
1.1	15 – 40
1.0	40 – 70
1.0	70 – 90
0.95	90 – 100
1.0	100

RULE 211

IF:

overrun or underrun

THEN:

add this value to the previous total for overruns or underruns.

3.4.3 Sample Rules For Detecting Time Variances

In addition to testing for cost variances, the system also tests for time variances. The following are typical rules for detecting time delays and time savings.

RULE 301

IF:

Actual Finish Time (AFT) < Estimated Finish Time (EFT)

THEN:

activity has time savings.

RULE 302

IF:

AFT > Late Finish Time (LFT)

THEN:

activity has time delay that will affect the remaining activities.

RULE 303

IF:

AFT > EFT and AFT < LFT

THEN:

activity has time delay that will not affect the remaining activities.

RULE 304

IF:

Early Start Time (EST) = Late Start Time (LST) or EFT = LFT or Total Float (TF) = 0

THEN:

activity is on critical path.

RULE 305

IF:

activity is on critical path and activity has time delay or savings

THEN:

the time delays or savings have a direct impact on the overall project.

RULE 306

IF:

AST < EST

THEN:

activity will probably finish early due to previous activities.

RULE 307

IF:

AST > LST

THEN:

activity will probably finish late due to previous activities.

RULE 308

IF:

(percent complete * estimated duration * adjustment value) < (accounting date – AST)

THEN:
activity will probably result in time delays.

RULE 309

IF:
(percent complete * estimated duration * adjustment value) > (accounting date – AST)

THEN:
activity will probably result in time savings.

RULE 310

IF:
activity has time savings or delays

THEN:
add this value to previous value for activities on this path.

3.5. Sample Consultation

The following transcript is a typical transaction between the system and a user. This is a simulated consultation for demonstrating the system operation. The session begins with the system requesting identification of the project. Once the project name is supplied, the system and user go through a series of interactions to complete the consultation. (User response is given in capital letters and is proceeded by "???". If a carriage return is provided after a "???" the system continues processing.)

Sample User Consultation

Enter project name –
??? LANGDON SPECIALTY STEEL PLANT

Processing Langdon Specialty Steel Plant. . .

Activity Number 12-10-01150-032 "Survey lot location and size" invalid percent complete. Enter new value –
??? WHY?

Percent complete = 200%
RULE 002
If: percent complete > 100
Then: invalid input

Enter new value –
??? 100

Activity Number 01-12-03204-200 "Unloading, sorting and piling of reinforcing bar" invalid Actual Start Time (AST). Enter new value (MM/DD/YR) –
??? WHY?

AST = 7/31/89
accounting date = 7/18/89
RULE 005
If AST > accounting date
Then: invalid input

Enter new value –
??? 7/13/89

Activity Number 12-11-02110-000 "Clear and Grub light trees to 6 in. dia." Please confirm or enter new value for percent complete (percent complete = 100% –
??? 100

Percent complete = 100. Please enter Activity Finish Time (MM/DD/YR) for activity –
??? WHY?

RULE 102
If: percent complete = 100
Then: AFT must exist

Enter AFT –
??? 6/20/89

All data is considered reasonable. Do you wish to check for cost and time variances?
??? YES

Processing Langdon Specialty Steel Plant . . .

Activity Number 12-13-02322-010 "Site grading. Dozer 300 ft. 65 H. P. 20 C.Y./hr."
has a final cost overrun of $6,732
???

Activity Number 12-13-02322-010 "Site grading. Dozer 300 ft. 65 H.P. 20 C.Y./hr."
has a time delay of 8 days. This will affect overall project completion time.

???

Activity Number 01-12-03302-045 "Place anchor bolts. 3/4" dia., 18" long" may finish with a cost savings of $910.
??? WHY?

percent complete = 67%
estimated cost = $7,830
adjustment value = 1.0
cost to date = $4,435

RULE 204
If: percent complete * estimated cost * adjustment value < cost to date
Then: activity will probably have a cost underrun.

Finished processing Langdon Specialty Steel Plant. Do you with to analyze any other proejcts?
??? NO

Processing complete.

4. An Advanced Project Monitoring Expert System For Scheduling And Purchasing Improvement

4.1. System Function

The previous expert system was basically a diagnostic system with a limited and direct scope of application. A more complex system might focus on scheduling and ordering improvements during construction. This application is more generative and requires more judgement and expertise in order to perform at the level of an experienced expert.

This system would be executed at the beginning of a project (i.e. before construction commences) and again whenever the project manager feels is appropriate. A cost control or project engineer would be required to execute the system and provide it with and additional information which may be requested. This system would require more computational time than the previous system for execution. However, because the system is not executed every week, the additional time should not present a problem.

Like the previous system, this system interacts with the project monitoring data base described in section 2.2. The previous system obtained all the information required for its execution from this data base. Due to the complex nature of its task, this expert system often need additional information. When a required piece of information is unknown, the system requests this data from the user.

In order to be effective, this system needs an extensive knowledge base. As stated earlier, one of the best means to obtain additional rules for the knowledge base is to put the expert system into practice and allow experienced professionals to offer their criticisms and ideas.

Due to the detail of this expert system, many of the rules pertain to specific types of activities. For example, a rule that is applicable to "FORM WORK" activities may not be appropriate for "EXCAVATION" actvities. Because many rules are activity specific, an uniform activity coding system is required in order for the system to distinguish between the various activity types. For demonstration purposes, this paper uses a Means Cost Data codes to provide a standard coding system with this capability.

In order to control the size of the knowledge base, the sample rules presented in this section are concerned with those activities involved in the foundation aspects of a construction project. This includes the following activities:

* Design
* Proceure materials
* Excavate
* Form
* Tie rebar
* Place rebar
* Place anchor bolts
* Pour concrete
* Strip forms
* Back fill
* Dress up

In order for this system to be applicable to other project activities, the knowledge base could be expanded to encompass all activity types.

Another requirement of a complex system is a well developed explanation facility. In a simple system, an explanation module which repeats the last rule which was "fired" is sufficient. However for a project manager to have confidence in any conclusion reached by this expert system, he must be able to understand the reasoning involved. The explanation module should be capable of explaining:

* how it arrived at a specific decision.
* why an alternate decision was not reached.
* how a piece of information was used or why the information was ignored.
* what decision were made for the various subproblems.
* and what are the current actions of the system.

In order to minizime the time required for execution, it is important that an efficient network strategy be applied. For this reason, rules concerning the knowledge base network and network planning must be established. For example:

IF:
    the schedule changes are suggested
THEN:
    Check purchase orders for material delivery.

The system would then check the purchase orders for the rescheduled activities and consider rules pertaining to delivery dates, such as:

IF:
    the scheduled delivery date is later than the date the material is required.
THEN:
    check if material can be delivered earlier or check for possible alternative supplier

These Meta-rules serve two purposes:

1. A series of rules may form a circuit and cause the system to repeat the series indefinitely. Meta-rules reduce the possibility of the system recursively "firing" the same set of rules.
2. Meta-rules direct the system in the most efficient manner by focusing on those rules with the highest probability of having a true pretense.

4.2. System Procedure

Prior to execution of the expert system, 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 summitted 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 which apply to all activity types are conidered before the activity specific rules. Then performing activity specific rules, the system reads the activity 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, large activities, involving large amounts 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 changes to the project network. The project can then be resubmitted to the scheduling 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 and problems and suggests ordering changes to the user.

4.3. Benefits

The execution the this expert system requires more effort and resources than the previous system. However, its use is justified through the additional benefits.

* An expert system of this type eliminates the need for project engineer to perform the same function.
* By analyzing all activities and their material orders, the system insures adequate quantities and timely delivery of material.
* Recommendations made by this system may shorten project construction time or reduce project costs.
* Computer are extremely efficient and thorough when processing large amounts of data. This eliminates any human error and gives a project manager more confidence in the project schedule.
* Formalization of this knowledge enables a better understanding of the entire process.
* By analyzing the required quantities of labor and equipment, the expert system can perform resource levelling. This minimizes equipment rentals, personnel layoffs and maintains a steady requirement of resources.
* A scheduler may not analyze all aspects of a project or may not know as much as an experienced expert. An expert system provides a consistent analysis of the project.
* Analyzing the schedule during project construction allows the schedule to reflect activity to date.

4.4. Sample Rules

5.4.1 Sample Rules for Scheduling Improvement

When the system is executed, the following rules are considered for scheduling improvements:

RULE 401

IF:

Schedule has been significantly changed

THEN:

re-run CPM scheduling program on the remaining activities in the network.

RULE 402

IF:

schedule is changed

THEN:

check material orders and delivery times.

RULE 403

IF:

Predecessor Node (PN) of one activity = Termination Node (TN) of another activity

THEN:

the one activity follows the other.

RULE 404

IF:

activities do not follow each other in the following sequence:

(1) Excavate (xx-xx-02316-xxx)
(2) Form (xx-xx-03103-xxx) Rebar (xx-xx-03204-xxx)
(3) Anchor Bolts (xx-xx-03302-xxx)
(4) Pour (xx-xx-03314-xxx)
(5) Backfill (xx-xx-02303-xxx)

THEN:

request user to correct the activity schedule.

RULE 405

IF:

estimated labor for a project week exceeds 1.25 time the average labor demand for the project

THEN:

labor demand for that project week is high.

RULE 406

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.

RULE 407

IF:

labor deman for a project week is high and labor demand for the week preceding or following and activity is low

THEN:

consider re-scheduling the activity to minimize fluctuations in the resource requirements.

RULE 408

IF:

EST of activity A > EST of activity B and < EFT of activity B

THEN:

the two activities are scheduled concurrently.

RULE 409

IF:

EST of activity A > EFT of activity B

THEN:

the two activities are scheduled at separate times.

RULE 410

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.

RULE 411

IF:

several small concrete pours are scheduled at separate times

THEN:

consider scheduling the activities at the same time to minimize crew fluctuations and have sufficiently large batches of concrete.

RULE 412

IF:

activity number is xx-xx-03314-xxx and estimated quantity of concrete is greater than 15 C.Y.

THEN:

activity is a large concrete pour.

RULE 413

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.

RULE 414

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.

RULE 415

IF:

very small (odd) concrete pours

THEN:

use these activities as fill-ins to keep crews active.

RULE 416

IF:

rebar tieing (xx-xx-03204-xxx) is not scheduled concurrently with excavation (xx-xx-02316-xxx) or forming (xx-xx-03103-xxx)

THEN:

change schedule to level iron worker requirements and condense schedule.

4.4.2. Sample Rules for Purchasing Improvement

After a new project schedule has been established, the system analyzes the project for potential ordering and inventory improvements. In the previous examples, the system analyzed the data on an activity by activity basis. In this example, the system operates through analyzis of each material type. In this example, the system operates considered based on the type of material. This focuses the attention of the system on a few activities. The system then analyzes these activities, purchase orders and inventory records to check for ordering or inventory improvements for each material.

RULE 501

IF:
material is concrete
THEN:
average delivery time is 3 days.

RULE 502

IF:
material is reinforing bar
THEN:
average delivery time is 3 weeks.

RULE 503

IF:
Material is anchor bolts
THEN:
average delivery time is 4 weeks.

RULE 504

IF:
material is formwork
THEN:
average delivery time is 2 weeks.

RULE 505

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.

RULE 506

IF:
inventory levels are not sufficient to last the defined time period (amount in inventory < amount required)
THEN:
check purchase orders.

RULE 507

IF:
(amount ordered through purchase orders + inventory level) < estimated quantity required during time period for all activities
THEN:
request user to issue change order.

RULE 508

IF:
date of scheduled delivery > date material is required
THEN:
request earlier delivery of material or check for possible alternative suppliers.

RULE 509

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.

RULE 510

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
- manpower availability.

RULE 511

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.

4.5. Sample Consultation

The following transaction demonstrates both the scheduling and ordering aspects of the 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 it reasoning.

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 requirement 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 Steel Plant. Do you with to analyze any other projects?
??? NO

Please make appropriate schedule changes.
Processing complete.

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.

Sample User Consultation

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 8/26/89. The activity is scheduled to begin on 8/12/89. 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"

Material has not yet been ordered and activity is scheduled to begin on 7/30/89.
??? 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 with to analyze any other projects?
??? NO

Please make appropriate ordering changes.
Processing complete.

5. Conclusions And Recommendations

This paper presented current research into expert systems as well as the update practice of civil and agricultural construction project monitoring. Several construction management of exprt systems in the field of project monitoring were discussed. Two of these expert systems were discussed in detail: (1) a system for verification of accounting data capable of detecting cost overruns and time delays, and (2) an advanced system which suggests scheduling and ordering improvements during the course of a project.

The sample rules which are presented for these two systems are only a subset of the many rules which are required to build a complete, working knowledge base. These rules are presented to illustrate the type and style of rules for an expert system. If the system is to be put into practice, the knowledge base should be expanded to include other activity types. Also, as the system is used, complaints and comments should be welcomed to facilitate the creation of additional rules in order to expand and improve the knowledge base.

In order for a system to function, these rules should form a complete network. This doesn't mean that every situation or problem should be included. A knowledge base may handle only a set of problems, but no breaks in the logic are permitted. If a rule is "fired", the conclusion of the rule must lead the system to another rule or to an action.

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 of civil and agricultural construction project monitoring could be developed for practical use right now. While the formation of this expert system may require a substantial investment, this would be justified through the benefits of the system.

One of the most difficult aspects of developing and expert system is the problem of representation of knowledge within the discipline. Through interviews with experts in the field, it is possible to obtain rules and knowledge concerning the problem domain. However, in order for a computer to manipulate this information, this knowledge must be formally stated. The representation of this knowledge must adequately characterize the rules and the network which form the expert's reasoning. This requires much planning and the formalization of knowledge which was previously unexpressed.

Another difficult aspect of constructing an expert system is the actual coding of the system. Several domain independent expert systems exist for assisting in the building of a system. These systems already contain the context, the inference engine, the explanation module and the knowledge acquisition system. A programmer used the existing system and the domain specific rules to form a knowledge base for an individual application. While domain independent systems are available, they are not simple to understand or easy to use. With the currently available systems, it is difficult to build an expert system. Currently, a computer programmer is required to encode the domain specific knowledge into the system.

As expert system research progresses, there are several items which require consideration. The most important of these is the development of domain independent system which allows the user to easily construct a new expert system. This system should permit the user to quickly and efficiently add or delete rules from the knowledge base. The system should also enable an expert in the field to build a complete new system without requiring a computer programmer for assistance. Also, if expert systems are to be considered intelligent systems a desired feature is the ability of the system to add rules to the system without human intervention.

Another requirement of this system is a good explanation module. This module should enable the user to easily understand the reasoning process and provide comprehensive answers to questions. Because the inference engine is a critical item in an expert system, care must be taken to ensure the continued development of efficient search and network procedures. As research progresses, reducing the execution time of expert systems will enhance their usefulness.

Because this is a new field, many of these problems have not yet been corrected. However, future expert system research will help eliminate these problems. In addition, research in other areas of computer science will also help improve expert systems including:

* voice recognition
* improved data base management systems
* increase speed and efficiency

* personal computers
* graphics and color graphics

As stated earlier, making systems more understandable and with human qualities will enhance their acceptance. However, people must realize that expert systems, like other computer programs, are merely tools to be used to perform a function. As with any other computer application, expert systems can be of little benefit until they are accepted, used and put into practice.

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