Intelligent Web-Based Project Management System For Large Scale Construction Projects

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Abstract

Large-scale projects necessarily involve many organizations coming from different geographical locations. The task of coordination and information sharing/exchange therefore becomes very challenging. Recently, web-based project management systems have been developed and applied in construction project management. In this paper, we present an intelligent web-based project management system (IWBPMS[1]) developed by us, which integrates Project Management, Knowledge Management (KM) and Artificial Intelligence (AI) technologies. The paper firstly discusses the advantages of using IWBPMS in project management, which is followed by an in-depth discussion on a number of AI techniques including Genetic Algorithms (GA), drawing-interpretation and case base reasoning. GA is a useful optimization algorithm loosely based on natural evolution. The use of GA in IWBPMS enables the system to provide optimal solutions for time-cost tradeoff problems in project scheduling. Drawing interpretation is an application of pattern recognition technology developed in computer science. The use of drawing interpretation techniques allows IWBPMS to automatically translate symbolic engineering drawing into meaningful engineering values & quantities. The adoption of these AI based techniques has greatly enhanced the capacity of the IWBPMS in dealing with complex managerial problems in large-scale products. With the intelligent supports embedded in the IWBPMS, decision making procedure will no longer appear to be a blind-searching process and project managers will not only be better informed, but also be given more efficient tools in tackling problems in managing large scale project.

Introduction

The construction industry is an information rich industry, both in terms of the information it generates and exchange among participants, as well as the information it absorbs from outside sources (Abdelsayed and Navod 1999). The effective management and transfer of information is crucially important to the successful completion of construction projects. Large-scale projects necessarily involve more organizations coming from different geographical locations. The task of coordination and information sharing/exchange therefore becomes very challenging Although some IT tools such as email, video-conferencing, electronic networking, multimedia technologies, have been used to enhance communication and data/information transfer, these tools are used in a discrete and uncoordinated manner. Integration of these tools can certainly improve the efficiency and effectiveness. On the other hand, the fragmental, dynamic and one-off nature of the construction project management processes implies that without an integrated information system, project-specific information cannot be stored appropriately for generating knowledge and future use. Moreover, it has been discovered that up to 50% of project managers' time is spent on searching for required information (Edwards et al. 1996) This contributes significantly to the efficiency loss during the project management.

In order to solve these problems, internet technology has been applied recently to speed up and simplify communications, to share information among different participants of construction projects. Veshosky (1998) conducted a survey among 14 leading engineering and construction companies. The survey

[1] *IWBPMS is a general term widely used in the area of construction IT research.*

indicated that 6 companies out of the 14 used Local Area Network (LAN), and 6 had both LAN and dedicated Wide Area Networks (WAN). Rushdi and Retik (1997) suggested that virtual teams provide new possibilities in the construction industry of replacing face-to-face meetings that are expensive and time-consuming for distant participants.

In this paper, we present the IWBPMS which can not only serve as a repository for project-specific information that can be accessed by all project participants, but also be able to acquire knowledge from previous cases of critical issues and experiences using data mining techniques. In order to clearly describe this system, it is necessary to identify some of the typical problems that are often encountered in the process of project management Then, the computational model of IWBPMS is presented, which is followed by an example of using the system in project management.

Information Flow Model

An information flow model is developed for IWBPMS in order to define system components and their interactions within the overall information flow and sharing process. The model is based on a repository of all project information at different stages. The repository, or database, resides on a main server to ensure the security and integrity of data. The model is composed of four main components. The daily site report (DSR) component collects and stores information regarding daily site activities and produces schedule data. The schedule control (SC) component enables updating schedule and produces schedule reports. The document management (DM) component provides a convenient tool for users to manage different project files generated during the projects. The critical issues (CI) model keeps a track record of all important issues occurred or might occur during the projects. The model components and their interactions are illustrated in Figure 1.

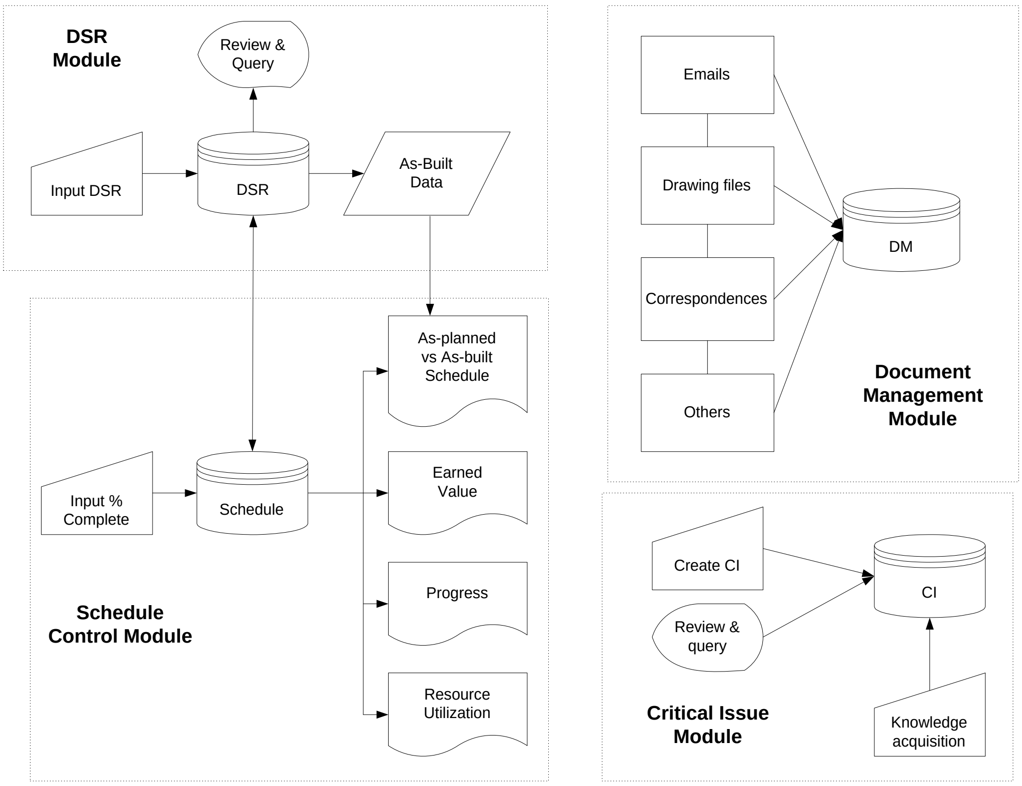
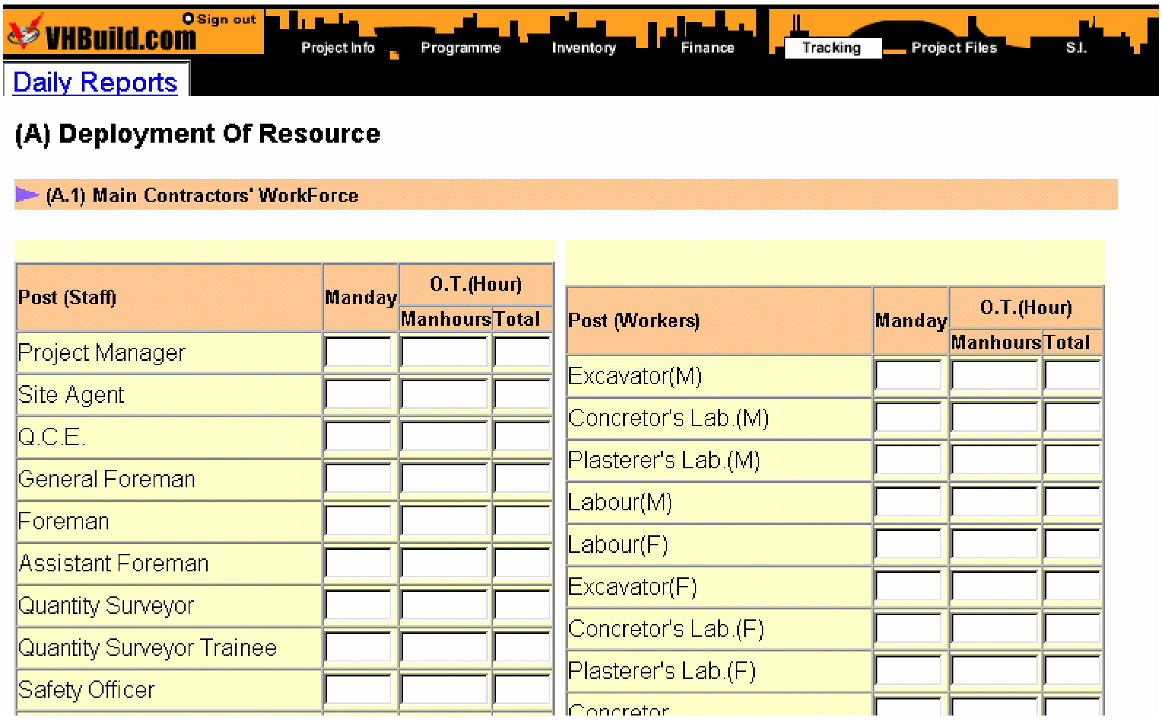


Figure 1: Components of IWBPMS

The four components are further described in the following sections.

Daily Site Report Module

Daily site report (DSR) provide project managers with a comprehensive record of site activities. The reports are prepared by creating and completing electronic forms. The format and content of the electronic forms are determined by users based on the level of details they required. The DSR allows users to register information regarding the types and descriptions of work done on a daily basis, and problems encountered. It can also keep track of periods of no work or inactivity. In addition, the DSR can keep records of types and quantities of resources allocated and used. Figure 2 shows an example of daily site report.


VHBuild.com Sign out Project Info Programme Inventory Finance Tracking Project Files S.I.

Daily Reports

(A) Deployment Of Resource

(A.1) Main Contractors' WorkForce

Post (Staff)	Manday	O.T.(Hour) Manhours	Total
Project Manager			
Site Agent			
Q.C.E.			
General Foreman			
Foreman			
Assistant Foreman			
Quantity Surveyor			
Quantity Surveyor Trainee			
Safety Officer			

Post (Workers)	Manday	O.T.(Hour) Manhours	Total
Excavator(M)			
Concretor's Lab.(M)			
Plasterer's Lab.(M)			
Labour(M)			
Labour(F)			
Excavator(F)			
Concretor's Lab.(F)			
Plasterer's Lab.(F)			
Concretor			

Figure 2: An example of DSR

Information collected from daily site reports can be used to generate as-built factual data. The availability of daily site reports allows project participants to review project information in real time, because these site reports are available at the end of a day rather then at the end of each month.

Schedule Control Module

The schedule control module provides access to “on-line” schedule information. Users have the option to select the level of details of the schedule to view. Typically, the schedule control module an present the percentage of an activity either in an-hours or dollars. The as-built schedule data, which is collected using daily site reports, an be summarized and incorporated into the schedule to form the realistic as-built representation of an activity’s progress.

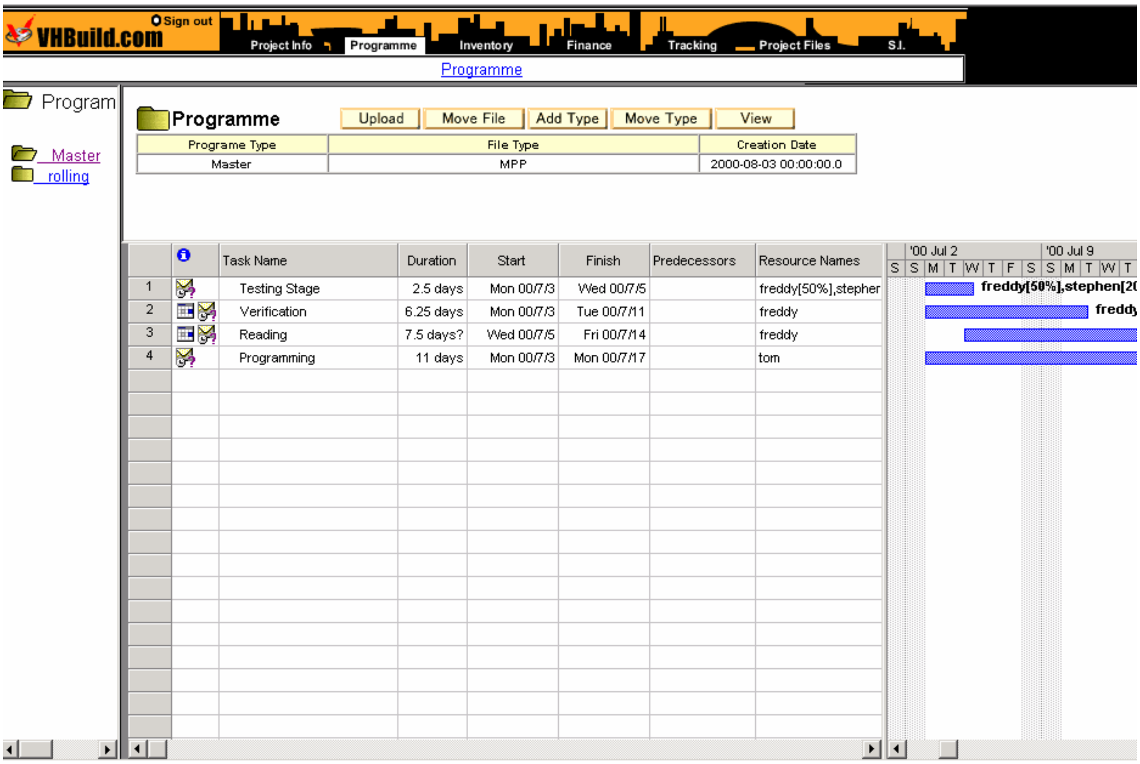


Figure 3: Schedule Control

Figure 3 is a screen dump of the schedule control module. From Figure 3, it can be seen that the comparison between the as-built and as-planned is presented graphically.

Document Management Module

A document management system is developed for the users to manage incoming and outgoing correspondences, drawings, and other useful documents. This system allows users to view documents in various formats including DWG, MSWORD, scanned images, and etc. A searching mechanism is also available for retrieving documents. In addition, documents can be exchanges conveniently among project participants using the upload/download functions. Figure 4 indicates the interface of the document management module.

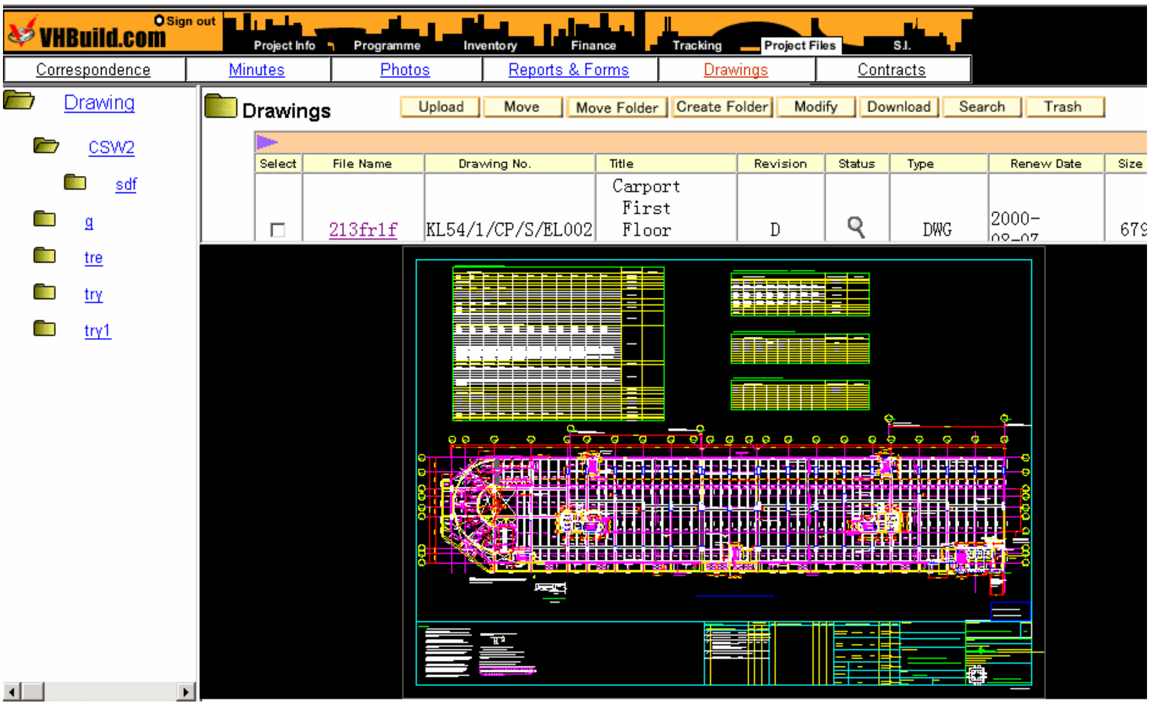


Figure 4: Document Management Module

The availability of the document management module maintains the integrity of project documents.

Critical Issue Module

The critical issue module enables project managers to record critical issues and/or events which have occurred or might occur during the project. By entering the nature of the critical issues which includes the consequences, reasons and related descriptions and files, the system can store the critical issues for further use. These critical issues can be important site instructions from architects, potential hazards and threats to the projects. The critical issue module has the following major functions:

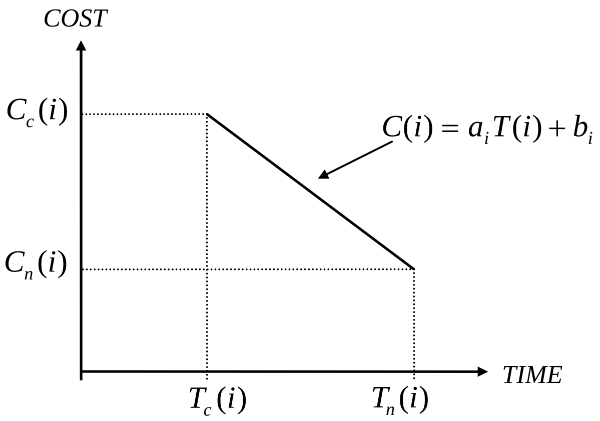
- Store and retrieve critical issues
- Advise the project managers on how to handle the critical issues
- Automatically update its knowledge base on the arrival of new critical issues using data mining techniques.

When a new critical issue is prepared and entered into the system, it is stored as a case that can be retrieved and reasoned using case-based reasoning techniques (Li 1996).

Time-Cost Optimization based on Genetic Algorithms

Time-cost optimisation problems in construction projects are characterised by the constraints on the time and cost requirements. Such problems are difficult to solve because they do not have unique solutions. Typically, if a project is running behind the scheduled plan, one option is to crash some activities on the critical path so that the target completion time can be met. It is necessary to note that not all activities are crashable, for example, ‘curing concrete’ is not a crashable activity. All activities concerned in this paper are selected as crashable activities. If durations of activities are crashed, it is inevitable that the cost of these activities will be increased considerably, owing to the general inefficiencies that will result from crowding the operation with labour and plant, and also the increase in the non-productive element of the overtime that is paid for in carrying out these activities.

In time-cost optimisation, the following terms are frequently used. The normal time for completing an activity is determined at by calculating the minimum cost (normal cost) for the activity. The minimum duration for the activity is known as the crash time, and the cost associated with the crash time is called crash cost, as indicated in Figure 5.



Note:

$C_n(i)$ *= normal cost for activity* i

$C_c(i)$ *= crash cost for activity* i

$T_n(i)$ *= normal time for activity* i

$T_c(i)$ *= crash time for activity* i

$T(i)$ *= intermediate time for activity* i

$C(i)$ *= intermediate time for activity* i

$a_i = \left(C_n(i) - C_c(i)\right) / \left(T_n(i) - T_c(i)\right)$

$b_i = \left(C_c(i)T_n(i) - C_n(i)T_c(i)\right) / \left(T_n(i) - T_c(i)\right)$

Fig. 5: Cost-Time relationship for activity i

The objective of a time-cost optimisation problem is to minimise the total cost incurred by crashing some activities in order to shorten the total duration to a targeted limit, and the form of the objective function is:

$$\text{minimise } C_t = \sum C_i = \sum \left(a_i T(i) + b_i\right) \tag{1}$$

subject to the constraints:

$$\sum T(i) = T_t \tag{2}$$

$$a_i = \left(C_n(i) - C_c(i)\right) / \left(T_n(i) - T_c(i)\right) \tag{3}$$

$$b_i = \left(C_c(i)T_n(i) - C_n(i)T_c(i)\right) / \left(T_n(i) - T_c(i)\right) \tag{4}$$

$$T_n(i) \le T(i) \le T_c(i) \tag{5}$$

in which, i $\in$ A = subset of crashable activities on the critical path, C_t is the total cost, and T_t is the total crashing time required in the project.

Genetic algorithms are a set of tools based on natural selection and the mechanisms of population genetics (Holland 1975, Goldberg 1989). GAs employ a random, yet directed, search for locating the globally optimal solution. Typically, a set of GAs require a representation scheme to encode feasible solutions to the optimisation problem. Usually a solution is represented as a linear string called chromosome whose length varies with each application. Some measure of fitness is applied to the solutions in order to construct better solutions. There are three basic operators in the basic GA system: Reproduction (or Selection), Crossover, and Mutation. Reproduction is a process in which strings are duplicated according to their fitness magnitude. Crossover is a process in which the newly reproduced strings are randomly coupled, and each couple of string partially exchange information. Mutation is the occasional random alteration of the value of one of the bits in the string.

A chromosome can be viewed as boxes arranged in a linear manner, as indicated in Figure 6. Each box (gene) in the string represents an activity on the critical path to be crashed. The number on the top of the box indicates the position of the activity in the critical path, and the content in the box is the time to be reduced from the duration of this activity.

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
2.5	*1.0*	*0*	*0.7*	*0.5*	*0*	*0.2*	*0*	*0*	*2.0*

Legend:

x — *activity number*

$\boxed{y}$ — *time to be reduced (crashed) from the duration of this activity*

Fig. *6*: Chromosomal Representation

Initially, a group of feasible solutions, which are encoded in strings, are given to the GA system. The fitness of solutions are evaluated by the objective function and its constraints. If a solution satisfies Equation (2), then it is a feasible solution, otherwise it is labelled as an infeasible solution and given a weight of 0. Equations (1), (3), (4) and (5) are applied only to feasible solutions to calculate the additional total cost incurred from time reduction. Maximum and minimum costs are generated and each solution is given a weight which is proportional to the difference of the maximum cost and the cost resulted from the particular solution. The solution that yields the minimum cost is given the highest weight, and the one with maximum cost is given a weight of 0.

Reproduction is a procedure where solutions with non-zero values of weights are selected and duplicated to the number given by their weights. For example, if a solution has a weight of 2, then it is selected and two exact replicas are made and entered into the next generation.

Crossover is performed by randomly selecting two members from the population and exchanging their chromosomal information. Crossover occurs only with some probability (p_c) and when solutions are not subject to crossover, they remain unmodified. It is stated that the power of GAs arises from crossover where a randomised exchange of genetic material is executed with a possibility that 'good' solutions can generate 'better' ones (Goldberg 1989).

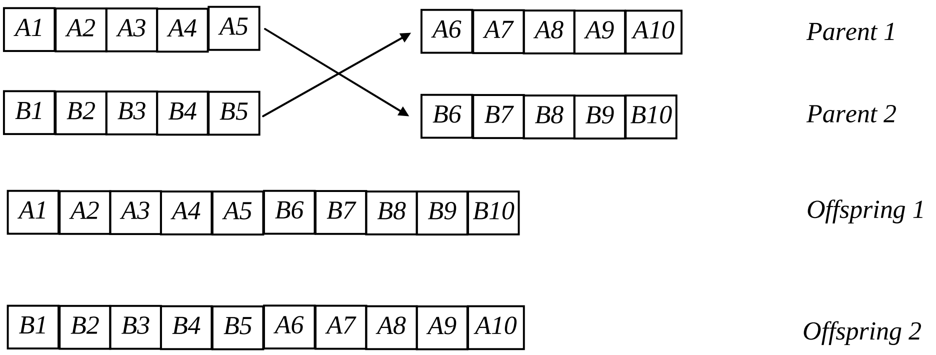


Fig. 7: Crossover

Figure 7 illustrates that two strings (parent 1 &2) are randomly selected and broke at a random point (at gene 5), and after the exchange of genetic material two new strings (Offspring 1 & 2) are generated.

Mutation involves the modification of the content of some genes of a solution with some probability (p_m). The role of mutation is to restore lost or unexplored genetic material into the population to prevent the premature converge of the GA to sub-optimal solutions. The GA system goes on by performing reproduction, crossover and mutation. After several generations, the best member of the population turns out to represent a very satisfactory solution of the problem. The balance between crossover and mutation is maintained by the values of p_c and p_m, and value ranges of p_c and p_m are normally within (0.5-1.0) and (0.001-0.05), respectively.

The GA based time-cost optimization technique has been implemented and integrated into the IWBPMS system. By using this system, optimal solutions to time-cost problems can be resolved quickly.

Rule-based Drawing Interpretation

In order to reduce the time and to improve the efficiency in steel reinforcement measurement, we developed a rule-based system that can automatically recognize drawing elements from scanned images of structural drawings, and then automatically measure the amount of steel reinforcement.

In order to interpret engineering drawings, a set of feature-based generic rules were developed to represent the knowledge and methods used for interpretation. Recognition and interpretation of engineering drawings is based on the identification of graphical features of drawings. We have classified features in construction engineering drawings into the following levels.

1. Pixel level: the most primitive representation
2. Graphics primitives level: the representation of graphics primitives such as line, arc circle and so on
3. Symbol level: representation of a group of graphics primitives
4. Element level: representation of a structure element
5. Frame level: Representation of the whole structure of a building

When engineering drawings are scanned and vectorised, drawings symbols are classified and interrelationships between them are analysed. The feature-based rules can then be applied onto the analysed drawings and quantities can be measured. The availability of such a rule-based drawing interpretation system largely reduced the time, and thus costs, needed for measuring steel reinforcement.

Knowledge Management: Case-Based Reasoning Approach

Case-based reasoning (CBR) is a problem solving strategy which is based on re-use of past solutions to address a new problem. Instead of representing knowledge as rules in rule-based expert systems, a case-based reasoning system maintains a case base that stores cases previously solved. When a new problem is encountered, the system retrieves cases similar to the new problem from its case base, selects the most similar one, and then converts the old solution to a new one for the new problem (Kolodner 1988). This technique is appealing because humans often make decisions in similar ways, and many attempts have been made to address CBR as a scientific cognitive model (Kolodner 1988).

There are two important operators in a case-based reasoning system: select and adapt. Select is the means of retrieving the most similar case from the case base according to the features of the new problem. A weighted count of matching features provides one way to select the best case; however, this does not take into account the fact that the case itself may determine the importance of a feature. Some approaches to finding the best cases are: preference heuristics (Kolodner 1988), dimensional analysis (Rissland and Ashley 1988), and dynamically-changing weighted evaluation function (Stanfill 1987). Once the best case has been selected, it is necessary to adapt the solution of the case to fit the new problem as closely as possible. In adaptation, decisions have to be made about what stays the same and what changes. The two alternatives for reusing a previous construction situation are to replay the operators that produced the solution and to reuse the construction situation itself. These are identified by Carbonell (1986) as derivational analogies and transformational analogies. The second transfer the solution of an old case directly to that it satisfies the criteria of a new problem; whereas a derivational analogy modifies the problem-solving processes or techniques of an old case to construct paths that result in solutions to the new problem.

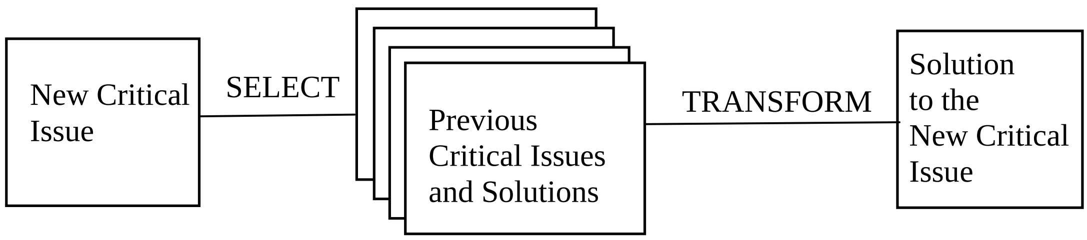


Figure 5: Case Based Reasoning Mechanism

A critical issue case is an abstract of information about a previous situation. The content of each case should include information that facilitates its reuse but not necessarily all the detail of the critical issue itself. Cases can be developed from a collection of previous critical issues. For our project, a critical issue case contained (1) case number and indexing keywords, (2) situational description addressing the background of the critical issue, (3) parties involved, (4) related documents, files and reasons for invoking the critical issue, (5) expected or actual results. A case has a root node indicating its indexing number and keywords representing important issues involved in the case. The retrieving process is based on searching for and matching keywords.

The retrieval and selection among cases entails the recognition of the relevance of each case to a new critical issue. The case base is indexed by the keywords of each case. When a new critical issue is defined as a set of issues and goals, the system traverses the cases according to the new definition of critical issue, and identifies the similarities between the cases and the new critical issue. The case with the highest similarity is then selected as a basis for generating a solution for the critical issue. To model this selection process, a weighted count of matching keywords can be applied. User interaction allows the set of matching keywords and their relative importance to be modified.

Case adaptation in IWBPMS forms the essence of solution generation. As a CBR model, the system assumes that case selection provides a specific case that is close to an acceptable solution and adapts those aspects of the case that are inconsistent. The selected case should contain most issues and goals that define the problem of a critical issue to be resolved. Knowledge used in case adaptation includes heuristics, common senses and issues, case base, and proportional relations. Modify reservation values, introduce new issues/goals, and select additional cases are three techniques of case adaptation.

Impact on Large Scale Project Management

As stated previously, large scale projects necessarily involve many participants who are situated over geographically distant locations. The use of web-based project management systems such as the IWBPMS, will enable an efficient information exchange and sharing among project participants. The intelligent aids equipped with IWBPMS, including the GA based time-cost optimization method, the case-based reasoning system for knowledge generation and management, extend the users' ability to make quick and better decisions.

Specifically, with the use of IWBPMS, the time spent on delivering project information can be shortened from days to seconds. The client can monitor the progress of the projects from viewing the latest photos and progress reports, without the need to go and inspect the sites. Designers, engineers, contractors and suppliers can communicate over the system which acts as the backbone of communication. As the first step toward establishing a virtual enterprise, the IWBPMS has virtually brought project participants together so that the geographical distances between them are no longer a barrier to project cooperation.

On the other hand, the capacity of IWBPMS at supporting knowledge management transfers the practice of project management to the process of accumulating and managing knowledge. Traditionally, construction knowledge is largely gained and accumulated through professionals who are directly engaged in the practices on the basis of piece-meal and individual processes. The accumulated knowledge cannot be shared among professionals, nor be transmitted to others. The use of the IWBPMS enables users to firstly register all the project data and information into a database. The registered data and information can then be shared by all the participants, and be re-used in other projects. By using case-based reasoning, the registered information can be used to distill knowledge which can be shared by all people working in the construction industry.

Summary and Concluding Remarks

The construction industry is an information rich industry. How to efficiently exchange information among various project participants, as well as to provide a useful tool to facilitate knowledge management have always been a major concern. In this paper, we present IWBPMS, an easy to use system that allows multiple access to project information from different locations by different project participants. The system incorporates a common work breakdown structure to avoid duplication data among databases implemented to store various aspects of project information. One unique feature of the system is that it utilizes a number of intelligent decision support systems, including genetic algorithms based time-cost optimization, rule-based drawing interpretation, and case-based reasoning mechanism which enable users to obtain intelligent support when dealing with complex decision-making situations in managing large scale projects. The GA based technique ensures optimal solutions are available for time-cost tradeoff problems. The rule-based drawing interpretation technique considerably reduces the time and costs needs to measure steel reinforcements in engineering drawings. By storing and indexing previous cases of critical issues into a case base, the CBR mechanism transfers past problem solving experiences into a process of knowledge management.

The system has been implemented in a web-based environment with a main server containing project databases. With a desktop computer and a connection to the internet, users can get into the system from different locations. The first phase of development is completed and the system is undergoing a rigorous testing periods using real-world project data. Ongoing development will focus on the integration of different stages of project life cycle into the system. Specifically, essential functions will be provided to assist designers to coordinate and manage designs and to facilitate facility management. Moreover, we will also consolidate the first stage development by enhancing the data flow integration and to further improve the security of the system.

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