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An Information Integration Framework for Multi-Project Coordinated Management in AEC Industry

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Abstract: Different information formats and lack of data standard result in the difficult of the information sharing and exchange in AEC industry. And the needs of simultaneous management of multi-project and cross-organizational cooperation increase the complexity of information exchange. This study presents an information integration framework for multi-project coordinated management in AEC industry on the base of IFC and XML. A management information system which consists of three logical layers are developed to realize multi-project coordinated management. The main five function modules of the core layer are discussed in details.

Key words: Information integration, framework, multi-project, coordinated management, AEC industry

INTRODUCTION

Information technology and Internet have brought the AEC (Architecture Engineering Construction) industry into an informationization age. Widely use of computer software and websites in construction help to improve efficiency in many systems such as electronic document management, engineering calculation, budget, bid and tender and project management. In the field of engineering design, structural analysis appeared in 1960's, finite element method, parameter design and prefabricated component modeling came up in 1970's and various special Computer Aided Design (CAD) tools presented to market in 1980's[1]. Within the past few years, over 200 project management Application Service Providers (ASPs) have invested US$2.5 billion on the AEC industry, including considerable functions such as project document management, information searching and online procurement[2]. However, due to the different information formats and the lack of data standard, different information systems are separated from each other and information cannot be exchanged and used sufficiently. All these softwares only face to some special problems during engineering building, but they are not considered from the view of information sharing in the whole AEC industry. Take Chinese AEC industry for example, although above 90% architecture design enterprises adopt CAD tools to produce construction drawings with a dimensional accuracy and clarity, a large number of electronic documents cannot be used in the succeeding process of building construction, engineering consultant and facility management, which results in the repetition of basic work. In addition, the needs of simultaneous management of multi-projects and cross-organizational cooperation for most enterprises increase the complexity of information exchange. A typical organization would normally undertake several project commitments at the same time while each project involves many different partners[3]. So, companies participating in a construction project usually deploy different software programs which create inter-organizational incompatibility and an inherent barrier to information sharing[4].

Researches on the information integration for construction industry have been carried out from 1990's. A recent National Institute of Standards and Technology (NIST) report concluded that better data exchange and interoperability could reduce potential cost of $15.8 billion a year for the construction industry alone[5]. Latham report points out in Britain in 1999 that better application of IT could curtail 30% construction cost and shorten 15% time limit for a project (the Comptroller and Auditor General,[6].

Various systems' information sharing and cooperation depend on the uniform comprehension on the meaning, data expression and exchange standard. The purpose of this study is to solve the problem of information integration in AEC industry by use of the advanced technique standards such as IFC (Industry Foundation Classes) and XML (Extensible Markup Language). It includes the following two research questions:

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- What is the important role that IFC and XML play?
- How to realize multi-project coordinated management by use of the information integration framework ?

MATERIALS AND METHODS

Literature research: The literature in International Journal of Project Management (IJPM) and Project Management Journal (PMJ) during 1993-2005 are researched to find all articles about multi-project management, because IJPM and PMJ are regarded as the premier academic level journals of the project management[7]. The focus of multi-project firm research lies in the subjects of organization restructure, resource allocation, schedule plan and cost control etc. Engwall and Jerbrant[8] consider the resource allocation syndrome is the prime challenge of multi-project management.

Top journals in the field of IT in construction are also searched to review the articles in terms of IFC and XLM, including Journal of Automation in Construction, Building Research and Information and Journal of Construction Engineering and Management. Swee-lean and Nga-Na[9] present a conceptual model of a metadata-based information system for data exchange among Web-based documents for construction project management.

IFC is proposed by International Alliance for Interoperability (IAI). In 1995, the IAI was formed to provide interoperability between the software used by all building project participants. The intent is to provide a means of passing a complete, thorough and accurate building data model from the computer applications used by one participant to another, with no loss of information. The first complete version of IFC model was released in 1997, including the fields of architecture design, HVAC, facility management and cost budget. The latest version IFC2x expands IFC model fields and sets up a stable fundamental framework for the whole information model, under which IFC domain can be expanded by means of modularization. The information model is divided into two parts: platform and non-platform. Platform is relatively stable. New models can be added or expanded on the basis of stable parts that provide flexibility and expanded space. The various software developers, using the IAI standard, populate the IFC model with information in a format that can be shared among all disciplines involved in the building process. Thus, IFCs have the information universally shared by various special fields during project process.

XML issued by W3C (World Wide Web Consortium) is a new standard for data description and exchange on Internet. It is a set of regulation for defining semantics, which allows users to set up Document Type Definition (DTD) and tags for describing data. By using DTD and XML scheme for defining syntax and data structure of XML documents, the data transmission between client browser and database becomes reliable and smooth. And using structured XML document as medium, data could shift among heterogeneous databases. So, XML is suitable for information integration as a transaction standard on the Internet.

By literature research, we conclude a number of useful methods, approaches, techniques, rules, frameworks, models, arithmetic and so on, which enlighten us to form initial ideas about solving those two questions. These ideas are verified or accommodated in the case study.

The case study: In a recent consulting engagement, the authors were introduced to a large construction enterprise that has been handling 80-100 projects every year. Each project may last several years and cost millions of dollars. The projects are characterized according to their location and technical characteristics. However, their structures (in terms of activity and process) are rather similar. So, for the most part, they all have to go through similar activities that require joint resources.

Since the coordination and information sharing among departments and projects are rather complex, the firm created an integration framework and developed a specially designed management information system on the base of IFC and XLM to meet the challenging task of managing this multi-project environment. Finally, by the verification and modification of the ideas deriving from the literature research, we find a satisfying approach to multi-project management.

SYSTEM LOGICAL DESIGN OF THE INFORMATION INTEGRATION FRAMEWORK

System architecture: The information integration framework Fig. 1 is build up based on the intervention of IFC and XLM. It covers the entire project lifecycle, uses IFC as project product model and XLM as web business tools and fully takes into account the various users or stakeholders in AEC industry.

According to the above framework, we developed a management information system to manage process in multi-project environment, which is labeled MPCMS (Multi-Project Coordinated Management System). The designed logical architecture of MPCMS consists of three logical layers-the core layer, the outer layer and the extended layer Fig. 2.

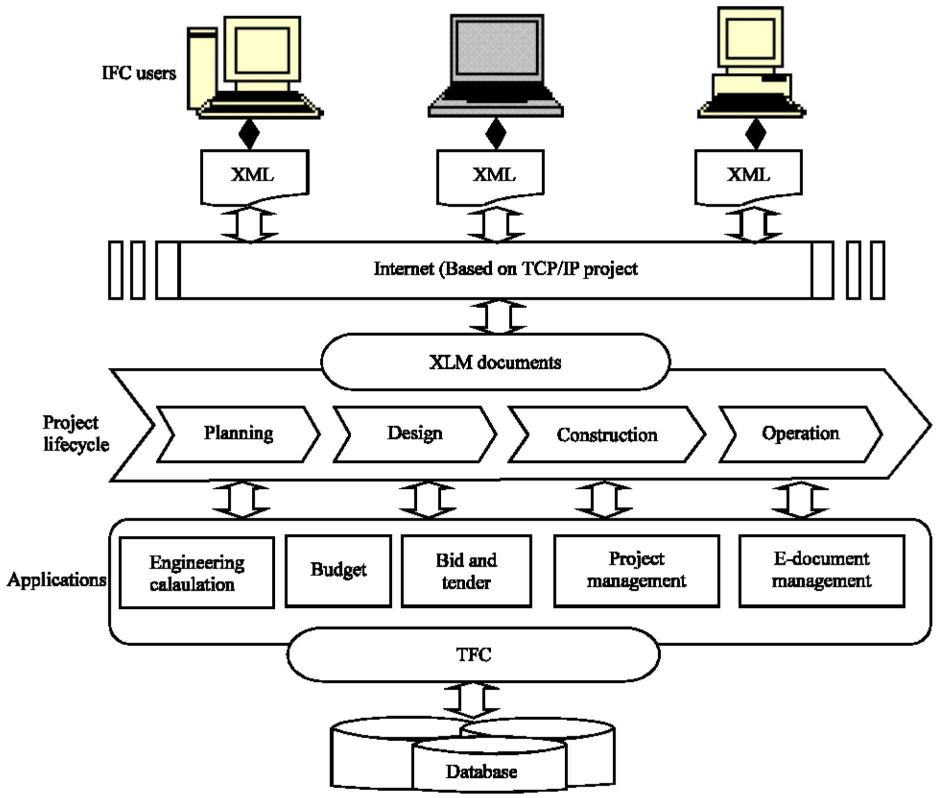

Fig. 1: An information integration framework based on IFC and XLM

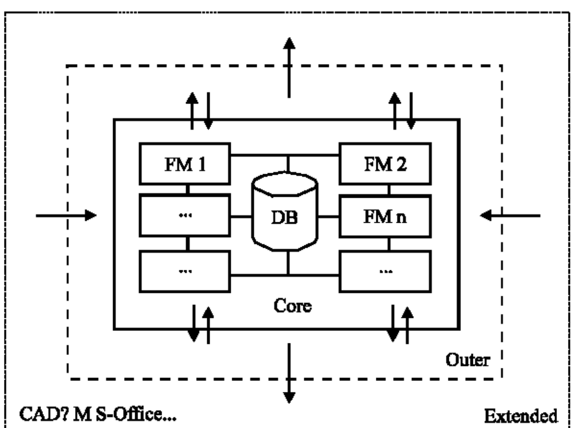

Fig. 2: Three logical layers of function modules

The core layer consists of five important function modules (abr. FM): resource allocation module, schedule and control module, evaluation module, contracts and customers module, logistics optimize module, which are the commonness, emphasis and difficulty of the framework. Business flows of the core layer are designed to accord with the IFC standard and specification. Data flows are designed to build on the public database.

The outer layer is designed to meet the need to deal with special processes of a firm. Data flows are integrated by loose connection, i.e., only design interfaces make of XML between different databases to exchange basic information.

The extended layer aims to aid the core layer and the outer layer, adding some flexibility, integrality and applicability. It integrates some commercial programs and software, such as Auto-CAD, MS-Office and so on. MPCMS only takes advantage of their basic functions, conducting limited data exchange.

IFC standard has been developing rapidly in the world. Many foreign software enterprises have the interoperability on the basis of IFC standard Table 1.

In next section, we discuss in technological details on how to realize the five difficult and complex function modules of the core layer.

The main function modules of the core layer and their components are shown in Fig. 3. The resource allocation module aims to allocate resources among activities of multiple projects, including finance, material, equipment and staff. The schedule and control module is designed to manage schedule, quality, cost and safety. The evaluation module can judge the performance of every task, rank the

Table 1: Some software systems supporting IFC

Company/ organization	Application	Purpose of application	Area of IFC model
Autodesk	Architectural desktop	AEC, architectural,CAD	Architecture
Bentley systems	Microstation triforma	AEC, architectural,CAD	Architecture
BCA singapore	IBP/IBS	Automatic submission and code checking	Architecture HVAC
Data design system	Electro partner, HVAC partner, Construction partner	Electro installation, HVAC installation, timber-frame construction	Architecture, construction, elctro and HVAC installation, interrior design (kitchen and bathrooms)
Fujitsu limited	Personal BLD	Architecture	Architecture
Graphisoft R and D	Architecture	AEC, architectural,CAD	Architecture
HAN dataport	EliteNT architecture,	Architectural design	Architecture
IAI FS	Claire project	Claire viewer	Architecture,FM,BS
Microsoft corporation	VISIO professional	Architecture, HVAC, electrical, FM	Architecture, HVAC, electrical,FM
NEC corporation	NcadArc WebCMN, IFC data server	Architecture internet service	Architecture

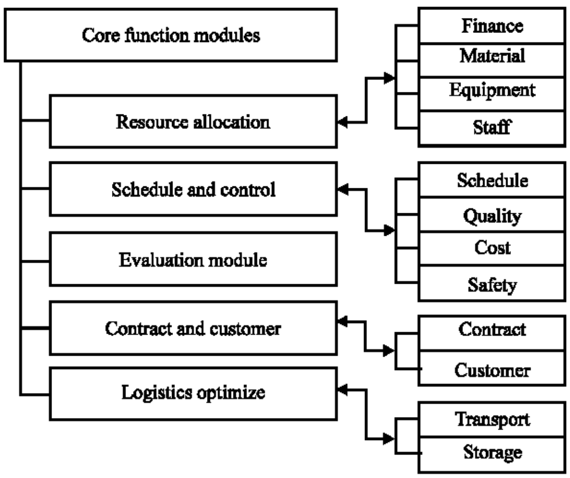

Fig. 3: Function module components

projects by scores and even find out the main reasons why a task fails to fulfill the aim. The contracts and customers module deals with the process of contract tracing and customer management. The logistics optimize module creates the optimal scheme for transportation and storage.

Function modules design

Resource allocation: Two-level Construction model and Genetic Algorithms. In a multi-project setting there are several projects that are accomplished side by side, while drawing, at least some, resources from a common resource pool. This means that the projects are integrated into the management control and reporting system of some common resource pool owner[10], e.g., a general manager.

Ghomi and Ashjari[11] discuss scheduling and allocation of common resources for a multi-project with stochastic task duration. Definition and application of a general approach are for multi-project resource allocation through a multi-channel queue. A simulation model is generated and executed with a simulation language (GPSS). However, it is an expensive and time-consuming process that requires verification to make sure that it does what it is intended to do, validation to insure that it represents the real system and sophisticated input and out analysis techniques to interpret the data. So, we adopt a Two-level Construction Model[12,13], instead of the simulation model.

Table 2: Parameters and variables in the model

Symbol	Definition
M	Resource number
P	Project number
P_1, P_2	Priority degree, P_1>>P_2
T_k	Planned minimum druation of project K
T^*_k	Required minimum druation of project K
R_{kl}	Amount of resource L allocatto project K
S_l	Total amount of resource L
w_{ki}	Finished time of the issue I in project K
D_{kij}	Duration time of activity I-J in project K
U_{kij}	Quantity of activity I-J in project K
x_{kij}	= 0, when activity I-J exists in project K; otherwise = 1
t_{kij}	Time decided by independent resource in project K

The following two assumptions are made to prepare the model shown in Table 2.

- The independent resource that an activity needs can be met, therefore, the duration of an activity is merely decided by sharing resource allocated.
- An activity is continuant, which means, only stop when finished if start.

Two-level construction mathematic model for resource allocation in multi-projects:

$$\min\{P_1\sum_{k=1}^{p}(\max(T_k - T_k^*, 0))^2 + P_2\sum_{l=1}^{m}\sum_{k=1}^{p}R_{kl}^2\} \quad (3\text{-}1a)$$

$$\text{s.t.}\sum_{k=1}^{p}R_{kl} \le S_l \quad l=1,2,...,m \quad (3\text{-}1b)$$

$$R_{kl} \ge 0 \quad k=1,2,...,p;\ \ l=1,2,...,m \quad (3\text{-}1c)$$

$$\min_k T_k = w_{kM} - w_{kl} \quad k=1,2,...,p \quad (3\text{-}1d)$$

$$s.t.\,x_{kij}\ (w_{kj}-w_{ki})\geq x_{kij}D_{kij} \quad (3\text{-}1e)$$

$i=1,...,M;\ j=1,...,M;\ k=1,\ ...,\ p$

$$x_{kij}D_{kij}=\begin{cases}\overline{U_{kij}}\\ R_{kl}\\ t_{kij}\end{cases} \quad (3\text{-}1f)$$

$l=1,2,...,m;\ i=1,...,M;\ j=1,...,M$

$$x_{kij}=\begin{cases}0\\1\end{cases} \quad (3\text{-}1g)$$

$l=1,2,...,m;\ j=1,...,M;\ k=1,...,p$

Definitions of parameters and variables in the model are shown in Table 2.

(3-1a) ~ (3-1c) describe the decision problem confronting the top-level managers, e.g., a general manager. The goal is minimize the consumption of shared

esources on the condition that maximize the degree of coherence between the required duration and planned duration.

(3-1d) ~ (3-1g) describe the decision problem confronting the low-level managers, e.g., a project manager. The goal is minimize the duration of one`s project.

The decision procedure of the model: Fistly, the top-level manager gives a scheme of resource allocation. Next the Low-level manager calculates the planned duration according to the resources allocated to his project. The results feed back to the top-level manager.Then he adjusts the primal scheme to meet the requriment of the goal function.The procedure continues until the optimal goal of top-level is achieved.

Genetic Algorithms (GA) is applied to search the optimal result, following five steps:

Step1, select encoding and generate the seed. Here adopt real number encoding mechanism.

Step2, design fitness functions: fistly use (3-2) to get a primal scheme; then use (3-3) when P_1 priority degree is achieved.

$$\max\{-\sum_{k=1}^{p}(\ \max\ (\ T_k-T_k^*,0))^2\ \} \quad (3\text{-}2)$$

$$\max\{-(\sum_{k=1}^{p}\ (\max\ (T_k-T_k^*,0))^2+\sum_{l=1}^{m}\sum_{k=1}^{p}R_{kl}^2)\ \} \quad (3\text{-}3)$$

Step3, reproduction operator: the possibility of reproduction Q_i is calculate by (3-4).

$$Q_i = q'(1\text{-}q)^{r\text{-}1} \quad (3\text{-}4)$$

q is the possibility of reproducting the optimal individual; r is serial number, P is the size of tribe.

$$q'=\frac{q}{1-(1-q)^p}$$

Step 4, crossover operator is shown in (3-6) and mutation operator is generated by (3-5).

$$x_i'=\begin{cases}x_i+(b_i-x_i)f(G) & \text{if } r_1\geq 0.5\\ x_i-(x_i-a_i)f(G) & \text{if } r_1<0.5\end{cases}$$
$$x_i\in(a_i,b_i);f(G)=(r_2(1\text{-}\frac{G}{G_{max}}))^b; \quad (3\text{-}5)$$

r_1, r_2 = U(0, 1); G is the number of generation; G_{max} is the max maximum number of generation;b is a formal parameter, let b = 3 or 4 here.

$$\begin{cases}\overline{X'}=r\overline{X}+(1-r)\overline{Y}\\ \overline{Y'}=(1-r)\overline{X}+r\overline{Y}\end{cases} \quad (3\text{-}6)$$

Step 5, end to get optimal results when reach the maximal iterative number.

Schedule and control: Critical chain: The early scheduling techniques are known as CPM (Critical Path Method) and PERT (Program Evaluation and Review Technique). CPM analyzes projects that have deterministic task durations, while PERT analyzes projects that have stochastic durations. Both techniques assume that the resources are unlimited available and dedicated to a single project[11,14].

Multiple Resource Constraint Project Scheduling Problems (RCPSP) have been proved to be a NP-hard problem[15]. Due to computational complexity, there are limited solution techniques available for it. And most are priority rule based heuristics. But their effect depends on the complexity of network, thus not suitable to extend to different kinds of projects.

Critical Chain (CC) is a popular project management technique in many multi-project organizations. It applies the Theory of Constraints (TOC) to offer a practical and easy method for planning, scheduling and control of multi-project systems[16]. This method is applied to support effectively the schedule and control module.

Evaluation: AHP, DSM and DMM: The evaluation module is design to evaluate and compare the performance of members in projects and also manage uncertainty in multiple project situations.

Two evaluating techniques are implemented in this module. One is Analytical Hierarchy Process (AHP), which is so mature that there is no need to be wordy. The other is the approach of Dependence Structure Matrix (DSM) a nd Domain Mapping Matrix (DMM), which has been discussed in details by Danilovic and Sandkull[17].

Contracts and customers: WBS and MC: According to contract, each project is broken down by the method Work Breakdown Structure (WBS), which results in the hierarchy object-task-activity. Milestones are preset in the task-level to provide a base line. Milestone Control (MC) technique is used to pre-alarm.

According to their roles, customers are categorized to five kinds: investor, sub-contractor, provider, monitor and governor. Different authority is granted to each kind. Digital signature is implemented in certificate authority.

Logistics optimize: Linear programming: Goal programming and dynamic programming create the optimal scheme for transportation. Five deterministic models are introduced to support the decision-making in storage and inventory control. Sensitivity analysis and parametric programming discuss some important factors how to influence the optimal results.

CONCLUSION

This study presents an information integration framework for multi-project coordinated management in AEC industry on the base of IFC and XML. Literature research reveals the important role of IFC and XML in information integration and the goal and emphasis of multi-project coordinated management. The case study verifies the validity of the framework by developing a management information system (MPCMS).

In the framework, IFC model is used as data standard and XML as a transaction standard on the Internet. According to the framework, MPCMS which consists of three logical layers are developed to realize multi-project coordinated management. The main five function modules of the core layer are discussed in details. In resource allocation module, the two-level construction model is built and Genetic Algorithms is applied to search the optimal result.

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