Enterprise Resource Planning for Construction Business Management

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Abstract: Enterprise resource planning (ERP) was originated in the manufacturing industry. It provides a general working environment for an enterprise to integrate its major business management functions with one single common database so that information can be shared and efficient communications can be achieved between management functions. This paper first briefs the ERP technology, its origin, and its current development in general. Based on the needs of running a construction enterprise, ERP shows its potential for the construction industry. However, the unique nature of the industry prevents a direct implementation of existing ERP systems, which are primarily developed for the manufacturing industry. This paper underlines the importance of the establishment of the basic theory for developing construction enterprise resource planning systems (CERP). A CERP must address the nature of the general industry practice. Fundamental features are identified and discussed in the paper. A three-tiered client/server architecture is proposed, with discussions on the functions and major components of each tier. Needed research issues are discussed, including CERP architectures, project management functions, advanced planning techniques, standardization of management functions, and modeling human intelligence. Construction management examples are incorporated into the discussions.

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Enterprise Resource Planning

Enterprise resource planning (ERP) has its origins in manufacturing and production planning systems (Fitzgerald 1992). The early systems were created three decades ago with the advent of materials requirement planning (MRP), which primarily organized the storage and allocation of production materials. Later, manufacturing resource planning, or MRP II, systems expanded those organizational efforts to include the allocation of production equipment and labor. The term ERP was born when the production-oriented systems were integrated with purchasing, financials, human resources, and other front-office applications to enhance management of all business operations across the enterprise. The scope of ERP offerings expanded in the mid-1990s to include other back-office functions such as order management, financial management, warehousing, distribution, quality control, asset management, and human resources. The range of functionality of ERP systems has further expanded in recent years to include more front-office functions, such as sales force, electronic commerce, and supply-chain systems (Hare 1999).

In a simple term, ERP is a computer program that provides a general working platform for all departments of an enterprise with their management functions being integrated into the program. The program runs off a single database so that all departments can easily share information and better communicate with each other. Today, an ERP system is more than traditional software. It is the information technology (IT) backbone of the corporate infrastructure (Bechler 1997). It provides an integrated multifunctional, multisite, and multinational business management tool (Thompson 1996; Gibson and Holland 1999; Tinham 1999).

ERP was a very fast-growing business in the 1990s. Its sales passed the $10 billion mark in 1998 (Hill 1999). The world's largest ERP providers include SAP, Oracle, PeopleSoft, and J. D. Edwards. SAP R/3 is the most popular system installed across the world (O'Conner and Dodd 1999; Jacobs and Whybark 2000). ERP systems have brought success to the manufacturing industry (Hare 1999). Some early adopters reported net return on investment ranging from 30 to 300% within a year after installing these systems. Oracle received 1 billion savings annually from the implemented ERP system (Report 2000, http://www.oracle.com). The great success sparked a leap in the research and development of ERP systems. Despite the reported business successes, a wide range of failures were also reported (Krasner 2000). ERP systems are expensive and difficult to implement. ERP implementation costs from $2 million to $130 million, according to a survey of 15 implementations (Ross 1999), and takes at least 6 months for a simple business with the accelerated R/3 system (Jacobs and Whybark 2000). Statistics show that the majority of implementations could not be completed in scheduled duration and within budget. A 1999 NSF-sponsored workshop realized the problems and concluded that a science base is not developed yet and that the ensemble of separated functional systems is untested on ERP technology.

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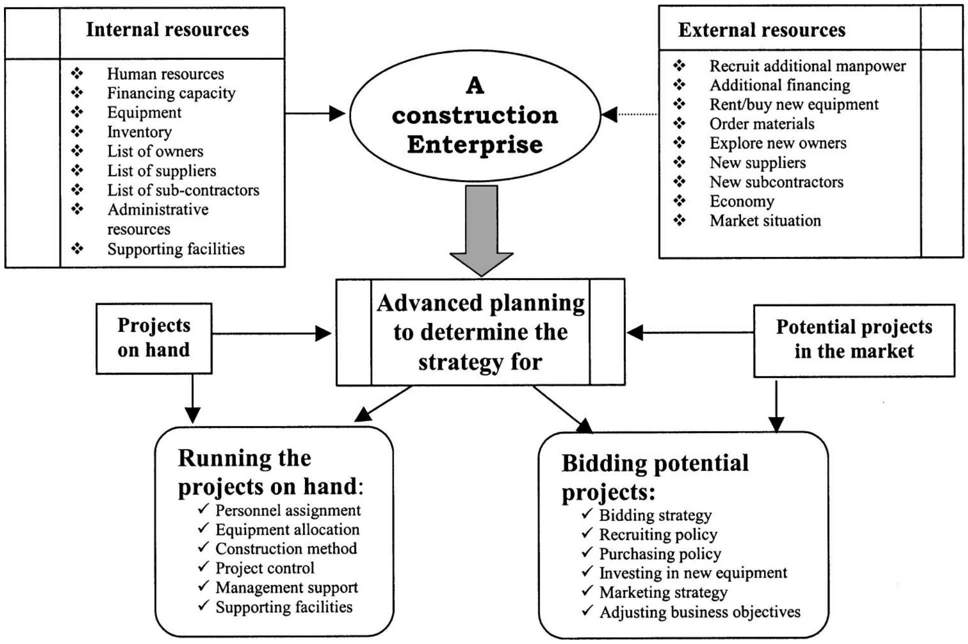

Fig. 1. Construction enterprise operation

Construction Enterprise Resource Planning

The availability of resources defines the production capability of a contractor. In general, a construction company can access two categories of resources: (1) internal resources, which the company owns; and (2) external resources, which the company can obtain from the open market at a price. The common objective is to maximize the usage of the company's internal resources and use the market to balance the company's operation. Given that construction projects are transient in nature, span different lengths of time periods, and require different resources, it is usually very difficult to achieve a balance between the production capability and the actual workload on hand for a construction enterprise all the time. In practice, a construction company has various ways to adjust its operations to approach such a balance. For instance, when the company does not have enough jobs, it may rent out some of its owned equipment and may bid lower prices on new projects. On the other hand, the contractor may rent outside equipment, recruit personnel, or request its employees to work overtime. Such enterprise-wide business decisions require using extensive information across the company and the market; otherwise, whether the company has made the best use of its owned and market available resources to serve its business objective remains a question. It is a common phenomenon to hear complaints from the people working in the construction industry. They complain of being overloaded and of being required to work overtime when the business is good; on the other hand, they worry about their job security if there is not enough work. Moreover, it is not unusual to see lower-than-cost bids when contractors are hungry for projects. Such a gambling strategy has driven many contractors out of business. Poor profits was found to be the top cause responsible for construction business failures (Kangari 1987).

Schematically, the operation of a construction enterprise can be described as shown in Fig. 1. The top of the figure presents the internal and external resources available to the enterprise. A solid line is used to represent the "owned-relationship," showing the available resources inside the enterprise. A dotted line is used to describe the "can-have ownership," for external resources that the company can get from the market at a price.

How can a construction enterprise optimize the utilization of its internal and external resources in order to maximize its business objective? Specifically, it must decide: (1) how to allocate corporate resources to the projects on hand; (2) whether or not and how to compete for additional resources in the market; and (3) the strategy for bidding projects and how to run these potential projects if they are awarded. This business decision-making process involves utilizing so much information across so many fields that conventional human subjective and segregated methods are not adequate. Instead, advanced planning techniques are needed. Internet technology provides a collaborative working environment for traditionally segregated management functions so that information can be shared and collaborative decisions can be effectively made. This leads to the conclusion that an internet-based integrated resource planning system is a potential solution for achieving construction enterprise-wide business automation.

Construction is the process of transforming materials and permanent equipment into a finished facility (Peurifoy et al. 1996). Compared with other industries, typically the manufacturing industry, the unique characteristics of the construction industry have been widely recognized (Tucker 1988; Oglesby 1990). From the business perspective, a construction company also operates in a different manner from its manufacturing counterpart. The uniqueness of the industry has prevented the direct implementation of many methods and concepts developed in the manufacturing industry, such as the mass production method. Such uniqueness forces researchers in the construction community to develop their own science base for the sustainability of this major industry. Construction enterprise resource planning (CERP) systems need to be studied and developed.

Basic Features Needed for Construction Enterprise Resource Planning System

To facilitate various users in the industry in accepting and using the system, a CERP system should be:

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- **Project-oriented:** The construction business is operated around projects. Each project is an end product to be delivered and is expected to be completed on time and within budget. After a contract is signed, the price for delivering the product is usually fixed and the profit from the project is fully determined by the cost, which is subsequently determined by the efficiency of the site operations. A CERP system should be able to manage ongoing projects with the ability of reporting and predicting progress status, cost status, profitability, and potential problems such as falling behind schedule and overrunning cost so that appropriate actions can be taken before problems occur. Moreover, the profit and progress of a project affect the overall performance of the enterprise. Project progress information must be timely and periodically summarized and reported to the corporate level to reflect the overall position of the company as far as financing requirements, cash flow, purchasing, equipment, and human resources. If there are conflicts among projects—for instance, competition for the same resources—corporate level decisions must be made by maximizing the overall interest of the enterprise. This feature does not apply to an ERP system for manufacturers.
- **Integrated:** A typical construction firm has two front-office functions (i.e., estimating and operations) and many back-office functions (e.g., accounting, engineering, contracting, procurement and purchasing, and equipment). These front and back offices rely on each other for information and interact with each other in making decisions for running ongoing projects and winning new projects. To achieve high efficiency and automation, these offices should be connected in an integrated system. The system must contain enterprise-wide information and every office should have its corresponding level of access to the same system according to its business functions. Any office can get the needed information and decisions online for supporting its management functions; also, every office can update its responsible databases and make decisions, which become available online for other offices. For instance, material deliveries updated by the purchasing office allow site managers to plan their site operations; a newly awarded project entered by the bidding division allows the operations division to schedule and plan its construction. Although all ERP systems must be integrated with various front- and back-office functions, a contractor has different offices and management functions from a manufacturer.
- **Paralleled and distributed:** Multiple management functions are concurrently carried out by managers in various offices across a company. Therefore, an integrated ERP system must use parallel and distributed technology in order to support multiple concurrent applications or requests. For example, an estimator may be searching the historic cost database for determining the bid price of a new project; at the same time, a cost engineer may be updating the database with recently completed project data. This feature is commonly needed for all ERP systems.
- **Open and expandable:** Applications are needed for supporting management functions, such as Timberline for estimating and Primavera Project Planner (P3) (Primavera Systems 1999) for scheduling and planning. An ERP system may interact with an application through three different approaches: (1) to run an application for responding a direct request—a user may start P3 to schedule a project; (2) to call an application for getting needed information—when preparing a progress payment request, the project manager needs the percent completion of the project, which can be calculated by a project information system; and (3) to facilitate two-way data exchanges between an application and the ERP system—after a new project is added using an estimating or scheduling application, the project data should be stored in the central database for users to access. It is well known that each construction enterprise has its own characteristics essential for its success. Applications will vary significantly from company to company. An open and expandable architecture allows a company to tailor its needed applications to fit its business needs. Meanwhile, new applications can be added to the environment and unneeded ones can be removed from the environment. Therefore, a high level of customization must be achieved with a minimal effort needed for an end user. This feature is much more highly required for a CERP than for a general ERP system.
- **Scalable:** Scalability is a common requirement for all ERP systems. Implementing an ERP system requires major capital investment and reengineering of business practices. An ERP system must be able to facilitate the strategic development of a company for many years to come. Scalability is reflected in the need for the system to accommodate expanded management functions. The functional offices of a construction enterprise are organized according to its tradition and size. A contractor may start implementing an ERP system with two functional modules, such as accounting and project management, so that only staff in the two offices can access the system at the initial stage. As time goes by, other functional modules and new users may be added to the system. Moreover, the construction business reflects the overall economic cycle. A scalable system is essential for a construction enterprise to meet rapidly expandable requirements and in the mean time to be flexible for economic down turns.
- **Remotely accessible:** Each project is constructed on a specific site, which may be hundreds or thousands of miles away from the head office. Remote accessibility enables project managers and other site personnel to remotely access central information such as purchasing and financing data; meanwhile, the head office can obtain the updated project progress information so that the senior management can assess the project performance and its impact on the company.
- **Transparent:** The construction industry is traditionally resistant to new technologies. One of the effective strategies to overcome this obstacle is to provide a self-explanatory mechanism in the system to allow users to trace down relevant reasoning for decisions or recommendations resulted in the system. For instance, the system may request a project manager (PM) to reschedule the site work of a project under his/her supervision. The reasoning behind may be explained as ‘‘The needed material is not available because Universal Supplier, Inc., is unable to deliver the material as scheduled, based on the delivery information updated by the purchasing office.’’
- **Reliable and robust:** This is a common feature required for all decision-supporting systems. For example, correct historical cost data must be retrieved from the cost database for supporting estimating; a purchase order must be reviewed and be approved in a right sequence; and a request for reserving a piece of equipment for a project must be processed accordingly and a reservation made, or the requester must be informed if the request cannot be satisfied.

Conceptual Construction Enterprise Resource Planning Architecture

ERP systems are commonly developed based on a three-tiered client/server architecture in order to offer the needed functional-

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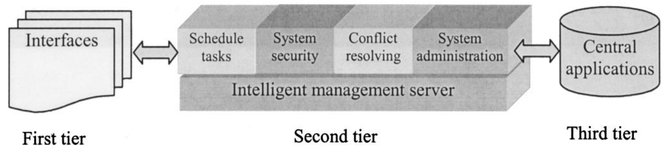

Fig. 2. Conceptual CERP architecture

ity, flexibility, scalability, and reliability. A CERP system can be based on the similar structure, but different components need to be built into the architecture. A conceptual architecture is shown in Fig. 2 with three tiers: user interfaces, management server, and applications.

First Tier: User Interfaces (Clients)

The primary function of the first tier is to present interfaces to various users across a construction enterprise. Users are categorized according to their office functions, such as payroll, accounting and financing, human resources, purchasing, equipment division, project management (operations), estimating and engineering, or corporate-level management. When a user logs onto the system, he/she is identified with his/her management responsibility and is presented with a corresponding interface, through which the user fulfills her/his management functions. A first-tier client depends on the second tier for identifying and executing needed applications on the third tier to perform expected management functions.

With authorization of the management server, a first-tier client can install specific applications and tools in its local environment in order to reduce unneeded communications. A local application may work independently in the local environment if no information is needed from other applications or the central databases. For instance, a project manager can view the project schedule information at his local computer. If a first-tier client updates any system data under his/her responsibility, the corresponding data source should be updated accordingly. Moreover, construction data are usually summarized on many levels of details. Should other related data be updated? For example, if an activity is updated with a new estimated quantity, its cost estimate should be updated, and the cost estimates of the related work packages and the total project cost must also be updated. An application that accesses the data source before the updating would get the old data, but an application would get the new data if the data retrieval takes place after the updating. Whether or not an application with the old data should be automatically reexecuted to reflect the updating should be determined by corresponding business rules. Updating policies should be defined for data sources. For example, a project's progress data may be collected and updated daily on the activity level; the project progress report may be generated on a weekly basis; and company-level summary on all ongoing projects may be updated monthly.

Second Tier: Management Server

The management server is the framework engine, which provides system administration and maintains central intelligence for facilitating clients and applications. It is the bridge between end users and applications. Process models function as the bridge. A process model is a list of interconnected management tasks that are executed for fulfilling a management function. After a request is raised, a corresponding process model will be identified and executed. When a process model is running, applications may be called by management tasks. Existing ERP systems provide a library of standard process models that are created based on the best industry/business practices. SAP R/3 contains more than 8,000 process models (Jacobs and Whybark 2000). For example, if a client is soliciting tenders for a new project, the bidding division may send a request for determining a bid price on the first tier. A corresponding process model will be fired assuming three tasks: (1) estimating direct cost; (2) estimating indirect cost; and (3) determining profit margin. The three tasks may be performed by different offices and may call applications as needed. After the process is completed, the request is accomplished with a recommended bid price.

If conflicts develop between different requests, they are resolved by the management server supported by intelligent agents or responsible managers. For instance, if two project managers are requesting the same piece of company-owned heavy equipment (e.g., backhoe excavator) for two different job sites to catch up with late schedules, an application will be called to recommend a solution based on the progress of the two projects and their impacts on the company. The system may turn to a relevant decision maker for a recommendation if the installed applications cannot solve the conflict.

The system scalability is achieved on this tier by defining and adding new users on the first tier and new applications on the third tier. As soon as a new user is registered with an assigned management responsibility, he/she can access the portion of the system corresponding to his/her responsibility. After a new application is added to the system, it becomes available for users in the system.

Third Tier: Applications

The third tier comprises the central database and applications. The central database contains cost data, project data, equipment information, and any other corporate-level information. Data warehousing is a new technology that provides a subject oriented, integrated, nonvolatile, and time-variant collection of data for an entire company (Inmon 1992). It should be mentioned that a construction enterprise has different data from a manufacturer. Construction applications can be organized into three categories: (1) corporate-level applications; (2) project-level applications; and (3) back-office applications. The corporate-level applications mainly aim at planning corporate resources, determining bidding strategy for new projects, determining the marketing strategy, determining the operation and business strategy of the enterprise, and providing corporate management tools. The project-level applications serve the following project functions: cost estimating, scheduling, planning, resources management, progress reporting and control, and quality assurance. Back-office applications include human resources, purchasing, warehousing, accounting, financing, and equipment management. All applications are installed independently in the third tier, as illustrated in Fig. 3.

Expected Benefits of Construction Enterprise Resource Planning

The major expected benefits of a CERP system include information sharing, improved transparency of management responsibilities, and improved management efficiency. These benefits will allow better business decisions to be made in a timely manner.

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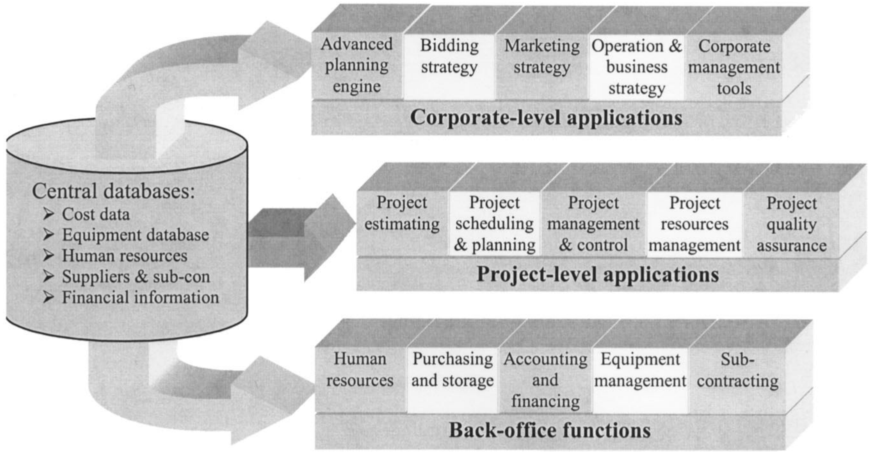

Fig. 3. Organization of applications in third tier

Information Sharing

In a traditional management environment, construction information is maintained by responsible offices across a company. A user must cross over organizational barriers between offices in order to get information that belongs to other offices. An ERP system runs off one single database. As soon as a piece of information is generated, it is stored in the central database and is available to all eligible users in the system. For example, if equipment data are available online, project managers would be able to use the information to reserve their needed equipment online, although the same result can be achieved in a traditional environment through back-and-forth communications between the project team and the equipment department. If the delivery status of materials is available online, project managers would be able to promptly notice a late delivery and to evaluate its impact on a project schedule.

Information sharing removes the necessity of regenerating or reentering the same information in different offices. Eliminating multiple data entries also help maintain data consistency and reduces human errors. For instance, the needed quantity of cement in a project is estimated by the staff in the estimating department. Using this information together with the project schedule, a purchasing officer can place an order. Traditionally, this information is reentered into various isolated systems such as scheduling and purchasing.

Improved Transparency of Management Responsibilities

Many management processes require a sequential set of tasks to be performed by various offices. For instance, a purchasing process involves preparing a purchase request, approval of the request, soliciting quotations from suppliers, sending a purchase order, and receiving the product. Traditional manual paper circulations between offices frequently cause delays or losses of information, or even errors in business decisions. For example, a purchase request from a project team may be misplaced somewhere so that the request is not processed. If the delivery information is not directly available to the project manager, the mistake may not be discovered until the material is needed on the job site. After the instance, it is very difficult to trace down the responsibility because the status of the request is not fully traced. The project team may criticize the purchasing staff, while the purchasing staff may argue that a request was never received.

An ERP system performs a management function by executing a corresponding process model that consists of management tasks. Tasks are performed one-by-one by following the sequence given in the model. A seamless collaboration between offices is achieved through the networked connections between offices. After one task is performed, the ERP system will move to the next task in the model. During the process, the system keeps all details regarding when a task can be performed and when and by whom a task is performed. If a purchase request is generated, it is traceable to when it is generated and when it is sent to the purchasing office. Therefore, the responsibility is clear if the request is not processed anywhere. Moreover, with the delivery status online, the project team can discover the problem if the request is not processed properly.

Improved Management Efficiency

An ERP system improves management efficiency through two improved practices: (1) providing timely consistent information; and (2) providing a coordinated decision-making environment. Making business decisions requires relevant information in a timely manner. In a traditional management environment, management is frequently confronted with different or even conflicting figures obtained from different sources. Decisions have to be delayed in order for the management to verify these figures. For instance, a consensus decision may be hard to reach for an ongoing project if the project team, the financial office, and the engineering department have presented different pictures for the project because they focused on different aspects, updated the project status at different time intervals, and/or did not communicate with each other during their updatings. In an ERP system, each piece of information has one single source and has one responsible party who may update it, so that all parties will have the same information.

The network technology eliminates the physical barriers between offices so that all offices work on their responsible tasks in a coordinated manner. A management process runs from one office to another and information flows from one office to another seamlessly. For example, after a purchase request is initiated, the request will automatically be transmitted to a responsible office (e.g., the financial controller's office) for approval as defined in the process model. All requests for approval are listed on the terminals in the controller's office. A control officer evaluates one

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request at a time. After being processed by the controller's office, a request continues its journey to the next office.

Research Issues

There is no report on the implementation of ERP systems in typical construction firms. The writers believe that it will be hard to sell the current ERP systems to the construction industry for two major reasons: high cost and suitability. More than 90% of construction firms are of a small to medium size. They cannot afford millions of dollars for implementing an ERP system. Moreover, existing ERP systems emphasize standardization and automation. They are well-suited for large scale standard and repetitive operations and management processes (Jacobs and Whybark 2000), but they do not quite fit the needs of the construction industry. Research is needed to develop an ERP knowledge base that addresses the nature and the needs of the industry. It will be an extremely complex endeavor. The needed research issues include but are not limited to the following areas.

CERP Architectures

A study conducted at the University of Texas at Austin, specifically investigated the SAP R/3 system for capital facility delivery (O'Conner and Dodd 1999). The report concluded that R/3 can handle many functional needs through three modules: (1) project systems (PS); (2) materials management (MM); and (3) plant maintenance (PM). These functions include cost management, schedule management, subcontractor management, construction planning, field equipment management, field materials warehouse management, procurement management, and facility operations and management. The report also identified the missing functions, including functionality for handling earned value, percent completion, and cost forecasts in determining project progress; functionality for handling project work breakdown structures, scheduling, and budgeting; functionality for project tracking and reporting; functionality for cash-flow planning and management; and improved functionality for reporting.

It should be noted that SAP and other ERP systems are not primarily developed for construction. A manufacturer and a contractor face totally different business complexities and challenges. On the production level, a manufacturer's challenges are to effectively manage a complex supplier chain around its products, including coordinating material suppliers, production facilities, warehousing facilities, distribution network, and costumers' demands; but a contractor's challenges are to win new projects and to ensure that all projects can achieve expected productivity levels and progresses. Many management functions essential to manufacturers are not needed for contractors, such as product ordering, warehousing, and distribution. On the other hand, managing a construction business requires many functions that are not necessarily essential to manufacturers, such as project cost estimating and project progress monitoring and control. An ERP system will be the IT backbone of an enterprise (Bechler 1997). It must address the culture and general practice of the business in order to achieve its expected objectives.

The construction business is project oriented. A CERP architecture should be established based on this business nature so that an ERP system can effectively support project-based estimating, scheduling, planning, procurement, resource allocation, monitoring, costing, billing, and controlling functions. Such an architecture will provide a familiar environment for construction users.

Existing ERP systems aim at large international corporations with multiproduct, multiproduction facilities across regions or countries and a wide range of costumers over the world. Such a wide range of requirements have resulted in huge scale and expensive ERP systems in today's market. If we develop an ERP architecture focusing only on the needs of typical construction firms, it would be able to effectively limit the size of the system. Consequently, the development and implementation costs will be significantly lower so that typical contractors can afford it.

Project Management Functions

To address the project-oriented nature of the construction business, project management functions must be enabled in a CERP system. Project management functions have been widely researched on project, process, and activity levels covering many areas such as estimating, planning, scheduling, resource allocation/leveling/optimization, productivity and improvement, and progress reporting/monitoring/control (Halpin and Riggs 1992; Popescu and Charoenngam 1994). Work is needed to integrate these results into a CERP system so that project management functions are available in an ERP environment.

A contractor usually performs multiple projects concurrently. Improvement in delivering single projects is not the business objective of a contractor. An ERP system is intended to improve the overall efficiency of an entire enterprise. Therefore, research is also needed to integrate project management functions into enterprise-level business administration to facilitate a two-way communication between projects and the company management. On one hand, the company policy and available resources affect the execution of all ongoing projects; on the other hand, the status of ongoing projects jointly determines the business performance of the company. Research is needed to determine how the integration can be established.

Research is also needed to study the internal interactions inside a company between projects and supporting back-office functions such as estimating, engineering, procurement, warehousing, equipment, accounting, and financing. The difficulty is that the interactions take place dynamically over the entire construction period of a project. For instance, after a change order is received, the project manager needs the estimating and/or engineering office's assistance to determine cost and schedule estimates to be submitted to the owner's representative/engineer.

Moreover, developing interfaces between an ERP system and the external systems of the business partners of the company is another challenge. Typically, a contractor deals with many parties in a project, including the owner, owner's representative, engineer, suppliers, and subcontractors. Today, many integrated project information systems (PIS) provide a networked environment for all parties involved in the project to share their information (e.g., http://www.citadon.com/). A PIS serves a specific project. It remains to be defined how it should be integrated into a CERP system.

Company-Level Resource-Allocation Techniques

Project- or process-level resource allocation, leveling, and optimization have been widely studied with common objectives such as meeting the needs of a project, maximizing the utilization/productivity of resources, or minimizing a project's duration/cost (Popescu and Charoenngam 1994). A contractor owns various resources such as equipment and crews. It may have insufficient or extra resources to meet the needs of its ongoing projects. Allocating available resources to ongoing projects is an important company-level business decision in order to maximize the overall

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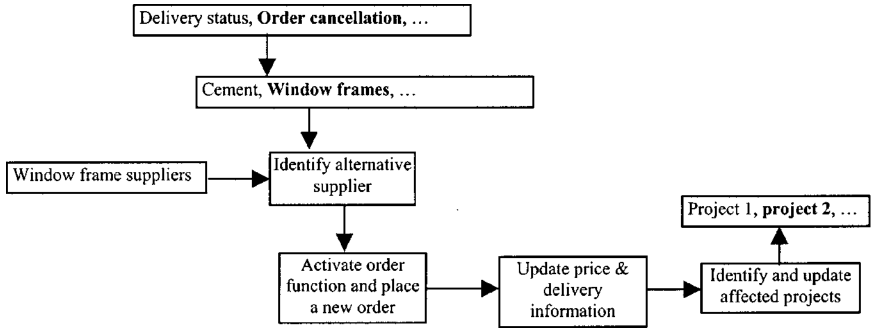

Fig. 4. Order cancellation management function

business objective of the company. Company-level resource-allocation techniques will provide quantitative tools to assist the senior management in making such resource-allocation decisions.

A construction project is usually far away from other projects and from the head office. Allocating a resource from one project to another is greatly constrained, and it always involves extra costs and time losses. Moreover, uncertainties in a construction project often limit the planning accuracy regarding when a resource is needed on a job site and/or when it can be released. Furthermore, some construction operations cannot be performed if a key or driving resource (e.g., crane) is not available. Contractors normally want to maximize the usage of key resources, but the utilization of other resources might be compromised. These factors must be considered while company-level resource-allocation techniques are studied.

Standardization versus Customization of Management Functions

Existing ERP systems achieve business management automation through standardization. A standard process model is created based on the best practice for performing a management function. Whenever the management function is needed, the same standard process will be executed in an ERP environment. At the installation stage of an ERP system, a company has the option whether or not to activate a standard model. If the company decides to use it, its staff must follow the standard process to execute the function when the ERP system is up and running. Therefore, standardization usually requires a company to reengineer its business practices. The benefits of standardization include improved management efficiency and reduced human errors, but it requires the staff in the company to adopt new working procedures that are different from what they were used to. Although it is possible to request an ERP provider to customize standard processes to fit a company's practices, it has proven expensive and time consuming, and presents a lack of compatibility with future releases of the ERP system (Krasner 2000). Customization is therefore not recommended by existing ERP providers.

There are two separate research issues: standardization and customization of construction management functions. Some management functions can be standardized based on the industry-wide practice. Standardizing a management function includes: (1) identifying management tasks; (2) linking these tasks logically; and (3) defining performance procedures of the tasks. For example, an order cancellation management process is shown in Fig. 4. If the purchase office is informed that an order for a batch of window frames is cancelled because the supplier is out of business, a purchasing officer can activate the process. In the order cancellation box, "window frames" is highlighted. An alternative supplier is identified by the officer from the alternative supplier list, and a new order is placed with the endorsement of the purchasing officer. The affected project and offices are then informed of the updated cost and delivery information. The project manager can update the job-site plan to accommodate the new delivery date.

On the other hand, the construction industry is characterized by nonstandardization in many areas. Many management processes cannot be standardized. Research is needed to develop corresponding technology that will allow custom management processes to be created with little or no effort (Kurucu 2001).

Modeling Human Intelligence in Decision-Making Processes

Although an ERP system is intended for business management automation, there will always be situations in which human expert decisions work better. Human intelligence and experience are widely recognized as one of the most important assets for the success of a construction business. How such knowledge can be incorporated into an ERP system remains to be studied.

An ERP system should not short-circuit decision makers. Governing rules must be developed for automated functions such as: (1) level of automation; (2) human responsibility; and (3) interactions between a human and the system. A decision maker may endorse a recommendation obtained from an automated process or overrule the system with a different decision as appropriate. For the order cancellation example illustrated above, if the purchasing officer is not pleased with the system-recommended alternative supplier, he/she may explore other alternatives by making phone calls or by searching webs. A new order may be placed differently from the one the system recommended. Moreover, an ERP may not be able to come up with a solution for many problems for various reasons (e.g., insufficient information), and it must turn to human experts for decisions. All of these remain challenges laying ahead in the process of developing the knowledge base of a CERP system.

Conclusion

This paper discussed ERP technology and its potential in the construction industry. Because existing ERP systems are primarily developed for the manufacturing industry, they can hardly meet the needs of the construction industry. A knowledge base is needed for developing CERP systems by addressing the nature and business culture of the industry. This paper proposed a three-

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tiered architecture for CERP systems and outlined the major features that a CERP system should have. Some key research issues are also elaborated. With this unprecedented challenge, developing the knowledge base requires a wide range of research activities and collaborations among researchers in the construction community.

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