STRATEGIC EXPLOITATION OF INFORMATION TECHNOLOGY IN MANAGEMENT OF LARGE-SCALE CONSTRUCTION PROJECTS

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ABSTRACT: This paper aims to clarify future direction of strategic exploitation of information technology (IT) in large construction firms through analysis on current IT implementation in large scale construction projects, such as super high-rise office buildings, high-rise condominiums and large-scale facilities with divided construction blocks. The research at first focuses on applied IT systems according to project specific constraints, then the best practices with key IT systems are analyzed:1) 3D-CAD systems for product management, 2) simulation and visualization systems for process management, 3) real-time monitoring and control system for production technology management, 4) communication system for organization management. Secondary, a strategy to exploit IT is described from project management viewpoints (product, process, technology and organization) by establishing concurrent and collaborative environment, an integrated production system in which engineering functions and management functions are systematically re-organized, and organizational knowledge management system depending on network systems and database management systems. Finally, current evaluation of the strategy and further research issues are also proposed.

KEYWORDS: strategy, information technology, project management, knowledge management

1. INTRODUCTION

More and more construction companies are finding IT to be their most strategic option in meeting increased competition in construction market. However, in the same way that there are many different perceptions and viewpoints regarding the strategic exploitation of IT. It is important to have a structured way to efficiently introduce information technology to improve engineering and management efficiency at executive management level, divisional function level and project level Different approaches such as technology-oriented approach, process-oriented approach, product-oriented approach and organization-oriented approach have been researched to establish effective strategy regarding the introduction of information technology. Many of the research efforts in this direction have been carried forth in the context of benchmarking the best practice among different industries, companies and processes [1], [2], [3].

The benchmarking is a methodology to assist construction firms by evaluating the performance of existing processes, functions, technologies and organizations in which they operate currently. In cases of automobile and aeroplane industry, the benchmarking is practically and effectively applied to evaluate efficiency and performance of a company or a factory to acknowledge their competitiveness in world-wide market, because they manufacture internationally standardized products. In contrast with those industry, construction industry is recognized as a diverse industry that constructs buildings and

facilities of high flexibility with low standard based on domestic building regulations, institutions and conditions.
Consequently, project-oriented comparative analysis should be introduced by defining types, size and characteristics of projects in which various IT systems are practically developed and implemented to improve engineering and management efficiency. The comparison and benchmarking of development and implementation with IT systems in different types of construction projects also illustrates a major strategy for technology research and development of a company.

2. BACKGROUND AND CURRENT IT APPLICATIONS

In Japanese construction industry, computerized technologies are at first introduced to structural engineering especially in the area of seismic analysis then to management of construction resources. Those applications were implemented on mainframe computer to enable super high-rise office buildings that had been started since middle of 1960's. However sophistication of structural engineering and construction technology depending on the market increase of super high-rise buildings, the application of project management system had been restricted to time scheduling due to low ability with high cost of computers and traditional management styles. Consequently, project management methodology had been explored through development of construction systems for super high-rise building systems regardless with IT. Then IT were applied to the construction systems as a part of research and were implemented at experimental level.
In the middle of 1980's, many large construction firms have started huge amount of investment to adapt innovative automation and information technologies to building construction based on increasing market. At first, many of the efforts were being carried forth in the context of the Computer Integrated Construction (CIC). CIC is viewed adaptation of CIM in manufacturing industry to construction industry.
To implement CIC, a systematic approach for applying computerization to building construction by illustrating future vision of building construction was introduced. The visions are represented as conceptual models to develop CIC by carefully investigating the functional distributions among planning, design, construction and required processes. For example, Shimizu's model was divided into three major functions: (1) Integrated design/construction planning, (2) factory automation system, (3) site automation system, and (4) Multi-project management system with central project data base. These conceptual models described strategies to exploit information technology among improved functions [4].
Since the project management associated with CIC posed stress on sharing and transmission of product information, logistic information and process information among the functions, information technology such as CAD systems including 3D-modeling; object-oriented programming; database management system; network-based communication systems; robotics and automated systems should play an important role in CIC implementation.
The concept was implemented as automated construction systems and integrated production information systems in the early 1990's. The implementation has promoted applications of such advanced information technologies to building construction supported by low cost of computers, improvement in software standardization, and extension of communication networks.
Since the middle of 1990's, Japanese construction industry has been involved in a severe recession. The economical environment forces construction companies to improve their

performance more and more by introducing information technology at whole business processes, functions and organizations.
In contrast with IT applications in the beginning of 1990's, computers are widely utilized in many business processes and in various types of construction projects, hardware and software should carefully be selected to considering company-wide utilization. Also, there are many types of existing services with utilization of information systems such as network, database and applications, outsourcing should be carefully investigated even with information systems required in core competence of a company. Thus company-wide IT strategy should be established and promoted through not only technological viewpoint but also business viewpoint, comprehensive and systematic exploitation of IT strategy to improve engineering and management efficiency is necessary.

3. COMPARATIVE ANALYSIS ON IT APPLICATIONS

The research focus here is to investigate project level strategy for IT exploitation by comparing IT implementations in several types of large-scale construction projects. The reasons why we focus large-scale construction projects are as follows: (1) Advanced technologies are usually developed and implemented in large-scale projects to systematically solve challenging problems at the time; (2) Technical resources, budget and time required to investigate, plan, implement, improve and evaluate strategies are allocated to large-scale construction projects rather than medium and small size projects; and (3) Comparative analysis associated with IT applications can be organizationally performed based on systemic perspectives at different levels of project management. Thus large-scale construction project can be viewed as a representative of company or factory to be evaluated through benchmarking.
Current challenging IT systems introduced to large-scale construction projects are 3D-CAD, systems for product design, simulation and visualization systems for engineering, planning and management, real-time monitoring and control system for production management, and communication system for daily site management and total project management, based on network and database systems. Since these systems are applied to each type of construction project through investigations to solve project specific problems and to improve management effectiveness under constraints, comparative analysis with individual IT systems are seemed to be useful to identify essential theory and mechanism in project management by IT applications.

Table 1 Major Project Constraints in Large-scale Construction Projects

GENERIC PROJECT CONSTRAINTS		High-rise Office Building	High-rise Condominium	Large-scale Facility
Building Specifications	Large amount of materials and labor	H	M	H
	Large underground substructure	H	L	L
Construction Environment	Sever site conditions	H	M	L
	Short construction period	H	H	H
	Multi-disciplinary in project management	H	H	H
	Complex project processes	H	L	L
Procurement Systems	Application of Design/Build system	L	H	M
	Dependency on special engineering contractor	M	L	H

3.1 3D-CAD system

In super high-rise office building, 3D-CAD system is not fully utilized in product design. The problems in 3D-CAD application for detail design and precise planning are usually caused by huge amount of data input required at the beginning of project stage. An attempt to share 3D-CAD data among several applications such as scheduling, material transportation planning and temporal facility planning usually be failed because product information is not fully established in early planning stage. On the other hand, 3D-CAD is efficiently utilized in large-scale facilities that contains complexity in physical shapes in product design. The application covers digitising of scale model, 3D computer modelling, checking of interference between structure and finishing, and modification of detail design as digitized product information. The success is led by high engineering capability in 3D modelling and visualization associated with 3D-CAD system. In case of high-rise condominium project, mechanical 3D-CAD is applied to investigation of interference among architecture, structure and mechanical equipment, and modification of product information is mainly performed in mechanical engineering. The high-rise condominium buildings extensively introduce open building system concept that eliminate interference among structure, finishing and mechanical works by clearly define product interfaces and decision making processes.

3.2 Simulation and visualization system

Major concern with project management is management of uncertainty brought by huge amount of materials and work forces, complicated project processes with multidisciplinary and complex site conditions especially in the center of a city. Construction simulations are challenging applications to improve project performance and to reduce risks in the project. In a large-scale construction project, construction simulations are usually performed at early planning stage to identify optimum combinations of scheduling, temporal facility planning, site layout planning and construction system planning. Among such applications, time scheduling and resource scheduling are key technologies to efficiently control quality, cost, delivery, safety and environmental effects of the project. The applications of scheduling systems in large-scale construction project have a similar feature regardless the types of project that is standardization of software to share schedule information among disciplines. 3D-CAD based construction planning system often used to simulate construction process and schedule depending on building systems, and to illustrates progress of the project.. Also simple excel-based scheduling systems are developed and utilized according to the project requirement that complement the control of the project [5].

3.3 Real-time monitoring and control system

In large-scale construction project, transportation of huge amount of materials, components and equipment is critical issues in schedule and cost control especially in case of high-rise building.

Material transportation control system organizes functions of logistics in outside of the site, transportation scheduling, arrangement of stockyard, monitoring and control of transportation machines. The management function of material transportation is usually established as a portion of monitoring and control center that incorporates material and construction waste transportation control via Intranet. The control systems utilize simulation system, monitoring system and engineering database to efficiently gather, store, process and transfer real-time transportation data among related functions.

Real-time monitoring system is also extensively applied to underground construction stages. Generally large-scale construction projects are designed to include full-site-size substructure,

excavation and construction of substructure must be carefully executed through precise structural engineering, construction planning and 24 hours monitoring. An Intranet based monitoring system has been applied to automatically transfer and store monitoring data to monitoring server and to share them among site engineers, supporting engineers in headquaters, branch office and institute of technology.
The application of IT systems with monitoring and control functions are well depend on Intranet technology and are in almost same utilization regardless the building types, because these functions are essential for large-scale construction projects.

3.4 Communication system

The main rolls of communication system in large-scale construction projects are: (1) to coordinate control functions of schedule, labor and safety as a daily site management system, (2) to settle project-wide rules to exchange information and data, and (3) to establish an information infrastructure to share engineering and management information for total project management based on Intranet and Extranet. Since large-scale construction projects have a feature of multidisciplinary management style and actually involve large amount of work forces, communication management by sharing management information via Intranet and Extranet is crucial.
Current applications of IT system for are divided into two types: (1) Daily site management system that incorporates meeting system, progress measurement system, and labor/safety control system using IC cards, and (2) Total project management system that integrates project information and technology information with separated construction blocks and work packages based on common applications and web-based IT systems such as web-groupware. The applications are selected according to the project specification and constrains with procurement system and are widely applied in large-scale construction projects, that imply future directions of IT-based project management methodology.

Reviewing IT applications in Large-scale construction project, the following issues are arisen to be further investigated:

- performance of information systems are well depend on the levels of integration of information technology and construction technologies such as open building systems, automated construction systems and industrialized production systems
- effectiveness of IT applications are rely on clear definitions of engineering and management functions of the project
- collaborative engineering and planning environment that fits for integrated applications of IT systems at early project stage is relevant
- major applications efficiently utilize network and database technologies that affect organizational efficiency of the project
- standardization effort improve productivity in information sharing and data transfer

Table 2 Major IT Applications in Large-scale Construction Projects

IT SYSTEMS	APPLIED FUNCTIONS	High-rise Office Building	High-rise Condominium	Large-scale Facility
3D-CAD	Digitiging and modeling	L	L	H
	3D-model-based engineering (structural analysis and facility design)	M	M	H
	3D-model-based product design (checking interference with structure and engineering facilities)	L	L	H
	Integrated Design/ construction Drawing (checking interference with structure and mechanical equipment)	L	H	M
	Construction simulation (process planning and resource scheduling)	H	H	H
Simulation/ Visualization	Construction system planning for superstructure	H	H	L
	Inverse construction planning for sub structure	H	M	L
	Project scheduling	M	M	H
	Procurement scheduling	H	M	H
	Resource scheduling for super structure	M	H	M
	Site-layout planning	M	H	M
	Temporal facility planning	H	H	M
	Material Transportation planning	H	H	L
	Construction waste evaluation	H	M	L
Monitoring/ Control	Intranet-based real-time monitoring of substructure	H	M	M
	Intranet-based real-time monitoring system for environmental aspects	M	M	H
	Monitoring of marital transportation machine	H	M	L
	Control of transportation facilities	H	M	L
Communication/ Network	Site management by meeting system	H	M	M
	Labor/safety control by IC cards, bar-codes and networks	H	H	H
	Intranet-based construction data & information sharing	H	H	H
	Intranet-based drawing & document management	L	H	M
	Extranet based knowledge and information sharing	L	H	L

4. IT STRATEGY FROM SYSTEMIC APPROACH

To investigate the future IT strategy, it is important to introduce a structured way. Originally project management supports a high level of coordination among product, process, technology and organization. The systemic approach will provide a well defined environment for the effective strategy for exploitation of the information technology to project management.

4.1 Management of technology by an integrated production system

Management of technology is defined as re-organization of potential construction technologies to efficiently resolve some of the difficulties associated with market demands for low cost and high standard and with increasing competition. Since construction technologies have been developed and stocked as individual or elemental technology to

solve specific problems in general. However they are efficient as technology itself, inappropriate combinations of those technologies introduced by individual and insufficient investigation often cause contradictions and complexities in construction stages, resulting in losses of time and expense. Therefore an organizationally integrated subsystems to simulate and define an optimal construction system as a best mixture of enable technologies within constraints are relevant.

In CIC concept, the construction system has been illustrated as a site automation system known as SMART (Shimizu Manufacturing system by Advanced Robotics Technology). The SMART system is a portion of strategy for construction innovation that covers construction technologies for super high-rise buildings including automated transportation system of prefabricated components, jacking-up systems of operating platform and real-time monitoring of simultaneous production processes with various machines.

However higher sophistication of an automated construction system is implemented, economical changes in construction market forces the technology to be modified either to reduce automation level of the construction system or to seek an alternative construction system based on other concept. The former approach is to restrict applications of automation areas to adjustment of transportation machines that are difficult in manual control The later approach is to focus on material transportation system and its control system by intensive utilization of network, database, monitoring and control systems. A systemic strategy is currently undertaken to explore and to combine the both restructuring and alternative approaches to be a new paradigm of physical construction system from a viewpoint of technology management .

The physical model of proposed construction system is composed by integrating engineering hardware and management software. The hardware system is consists of three physical engineering subsystems: (1) Construction plant system for superstructure to systematically incorporate transportation and assemly of prefabricated components and units with minimized temporal facilities and, (2) Construction plant system for substructure to widely introduce mechatoronics technology under simultenuos construction of superstructure and substructure, and (3) Site plant system to assemble components and to supply as units for construction plants.

The software system organizes two complemental management systems: (1) Resource management system that covers package planning and procurment of materials and labors, and (2) Production information management system that incorporates the functions of analysis, simulation, monitoring and contorol with three plant systems.

Among those subsystems, production information management system is an integral part of the proposed construction system to adopt optimum information technology according to characteristics of construction plants to improve engineering efficiency as a total construction system. Another function of production information management sysytem is to improve management efficiency by sharing production information with quality, cost, deivery, safety and environmental effects among participants of the project via project database and network systems.

Thus strategy in management of technology is to integrate construction technology and information technology by subdivision and restructuring of physical construction systems from a viewpoint of production information management.

4.2 Management of product and process by concurrent and collaborative environment

The decision making problems in large-scale construction project often caused by precise subdivision of project processes and functions, resulting in ineffective integration of information and technology especially in early project stages. The process-to-process and function-to-function information transmissions are recognized not only in internal project processes but also in external project processes in participants of clients, design/engineering firms, constructors and suppliers that decision making processes become further complicated. In case of large-scale construction projects, a lot of time is spent for exchange information among project participants through value engineering, constructability investigation based on incomplete detail design, and coordination with design documents and construction drawings. Consequently early introductions of construction knowledge and information in a form of concurrent design and construction planning function is important

To realize the function, two types of process integration are required: (1) Horizontal integration in a project organization as a collaborative work environment among designers, engineers and managers through optimal combinations of enable construction technology and information technology, and (2) Vertical integration in project processes as a concurrent work system among designers, engineers, constructors, fabricators and suppliers. The collaborative work environment in practice should be established as product design system by integrated design and construction drawing using CAD and EDI technologies.

The concurrent engineering environment for construction simulation should be established under production planning system using 3D-CAD system with formalized building/ construction system models and various simulation systems. The 3D-CAD applications should also be carefully investigated by considering efforts in data input and benefits by repetitive use of data. Currently product design and production planning are key issues towards total product and process innovation , and most of efforts should be undertaken in this direction with standardization of product and process models.

4.3 Management of organization by knowledge management system

Recent innovation in business process reengineering have provided an effective methodology to organizationally acquire, utilize and create useful knowledge associated with design, planning and management of construction projects. Originally IT applications to different levels of organization contain standardization of work flows and externalization of implicit knowledge to be utilized as well-organized processes and explicit knowledge to improve total efficiency of an organization. Remarkable progress in network and communication technology allows members of an organization to communicate each other and to share information and knowledge at real-time environment

Current IT-based applications to share information and knowledge among individuals, groups and organizations in a large-scale construction project are divided into four major functions: (1) Intranet-based real-time monitoring system to share information between site enginners and supporting engineers in headquaters, branch office and institute of technology; (2) Web-based information management system among clients, designers, enginners, constructors, fabricators and suppliers; (3) Total project management system among different contractors at site, and (4) Knowledge management system among same type of building projects such as high-rise condominium that locate at different construction site.

Since management of organization aims to integrate project functions to realize the customer satisfaction with a construction project including quality assurance and performance assurance under requirements and constraints, optimal combination of design, engineering,

procurement, construction and maintenance systems by organizational knowledge management are necessary. Therefore, life-cycle management of information throughout feasibility study to maintenance and renovation should also be highlighted. The research activities in this direction should mainly be promoted by the former CALS (Continuous Acquisition and Life-cycle Support) concept.

5. CONCLUSION

In large-scale construction project, IT is a potential resource to improve engineering and management efficiency. Through analysis on current IT applications, it is found that performance of IT systems are well depend on the levels of integration among information technology and construction technology, and efficiency of IT systems are also depend on the clear definition of engineering and management functions. Communication systems based on Intranet using web-groupware for project management are widely applied in large-scale construction projects, that imply future directions of IT-based project management methodology. To introduce effective IT systems to project management, IT strategy should be carefully investigated from systemic viewpoint to utilize concurrent and collaborative environment for product and process management, an integrated production system for production technology management and organizational knowledge management system for organization management.

Future research issues to establish frameworks to perform international comparison of IT strategy for project management, to evaluate IT-based management methodology and concept for project management and to establish IT-based organizational knowledge management mechanism in multidisciplinary projects are necessary.

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