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Review

The roles of information and communication technology (ICT) systems in construction supply chain management and barriers to their implementation

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Advances in information and communications technology (ICT) have impacted on supply chain management in various application scenarios, including the construction industry. Previous studies have shown that the use of appropriate ICT systems has the potential of integrating the plethora of supply chain participants, leading to successful accomplishment of end objectives. Nonetheless, these studies have also revealed the existence of certain unique elements in the ICT systems that do not gel or work in unison with other elements, thereby causing disruption to the entire construction industry supply chain mechanism. This paper is a review of past literature on supply chain management spanning the years 2000-2009. It focuses on the construction industry and delves into the characteristics of ICT systems that have resulted in successful integration and collaboration in the industry's supply chain. It reveals that ICT infrastructure is a double-edged sword that both facilitated and impeded the smooth implementation of a supply chain system in the construction industry.

Key words: Information and communication technology **(**ICT) systems, integration, construction supply chain, collaboration.

INTRODUCTION

Many believe that the construction industry is fragmented by nature (Brewer, 2004; Chiang, 2009; CIDB, 2009; Research Institute of Construction and Economy, 2009). In this respect, two main characteristics of fragmentation are mentioned (Langford and Male, 2001): one, the pre-demand nature of construction projects, whereby an owner must, of necessity, purchase the product prior to its completion; and two, the situated nature of projects at certain locations (the construction sites). In a construction project life cycle (PLC), the planning, design, procurement, construction and maintenance functions are separate disciplines that are executed at different phases. The cycle operates in an adverse environment that is characterized by small interactions between phases and disciplines (Engineers, 2005; Matheu, 2005; Vrijhoef and Koskela, 2000). Hence, communication, integration and collaboration amongst project participants in such a set-up are understandably difficult. To exacerbate matters, the industry is amorphous and diverse. It comprises multiple professions, occupations, and organizations in delivering projects (Langford and Male, 2001) and different market areas, like building, civil engineering, repair and maintenance, and materials manufacturing

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Abbreviations: **ICT**, Information and communication technology; **PLC**, project life cycle; **RFID**, radio frequency identification; **ERP**, enterprise resource planning; **IT**, information technology; **VR**, virtual reality; **WBDMS**, web-based document management system.

(Langford and Male, 2001; Seymour, 1987). According to Gajendran et al. (2003), this industry lacks effort to improve practices and productivity, and as a result, the industry continues to be fragmented. To address this problem, a number of solutions have long been offered. Nitithamayong and Skibniewski's (2004), for instance, propose the use of information and communication technology (ICT) systems to integrate the fragmented process and to address the problems of inadequate communication, the proliferation of adversarial relationships between parties, and low productivity.

In line with globalization and innovation of new products, the construction industry increasingly looks to ICT as a driver for many business and operational improvements. ICT permits management to examine the operations of an organisation in totality and not in a fragmented functionally isolated manner (Baghi and Skjoett-Larsen, 2002). According to Bennet (2001), ICT can better support projects and the utilization of resources, leading to increased profits. It can assist construction managers to make better decisions through enhanced communication. Cox and Ireland (2002) postulate that fragmentation of the construction supply chain can be addressed by greater effectiveness of project delivery using ICT. As the industry and its environment get more complex and subject to uncertainty, time and cost pressures, the need for useful ICT tools to support information supply chain is accentuated (Jaafari and Manivong, 1998). Many studies have demonstrated that the use of appropriate ICT systems can integrate the activities of the various supply chain participants, leading to greater collaboration among them (Gajendran et al., 2005; Brewer et al., 2005; Sun and Aouad, 2000). Participants in a supply chain can be linked by information technology (IT) throughout the PLC and across the supply chain. In a study by Min and Zhou (2002), the authors claimed that ICT provides the impetus for reengineering and supply chain cooperation. From the above mentioned studies, it can be surmised that ICT can play a pivotal role as an enabler in integrating the construction industry supply chain.

CONSTRUCTION SUPPLY CHAIN MANAGEMENT AND INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) SYSTEM AS ENABLER

To start with, numerous definitions have been accorded to construction supply chain management as viewed from different perspectives. One of the most significant definitions of construction supply chain refers to it as a network. Love et al. (2004), for instance, define it as the network of resources and activities that provide added value to the final customer in functions spanning project design, contract management, materials and services provision, raw materials production and delivery, and the management of the installations or resources. In a similar vein, Muya et al. (1999), interpret construction supply chain as a network of multiple organisations and relationships that include the flow of information, materials, services or products, and funds between the owner, designer, general contractors and suppliers.

Conversely, other researchers regard construction supply chain as a process integration. Li et al. (2007) define it as the integration of the construction business network, from original suppliers of materials, products, and services to the end users. This view incorporates the construction clients and other stakeholders into the chain, a position that is also supported by Fisher and Morledge (2002). The latter refer to it as the coordination of inter-organisational decision making and the integration of key construction business processes involving key members of the supply chain.

Yet other researchers stress the operational process involved. For example, Saad et al. (2002) define construction supply chain management as a construction process that starts from the initial demand by the client, through to design, construction, maintenance, replacement and eventual demolition of the projects. In this respect, it scopes in all the organisations involved - the client, the designer, the general contractor, the subcontractor, and the suppliers. From these prominent definitions, it can be summarised that construction supply chain management is an integrated process of all the activities involved in the different stages, alongside the human resources that provide added values in the supply chain.

There is a common view that ICT has a profound impact on supply chain management. Indeed, many researchers have addressed its value (Auramo et al., 2005; Lee and Wang, 2001; Leveray, 2000; van Hoek, 2001) in reducing cycle times and inventories, minimising bullwhip effect and improving the effectiveness of distribution channels (Leveray, 2000). A classic example of a successful deployment of web-based ICT solutions to restructure internal operations and integrate processes involving supply chain participants is Cisco, which reported a savings of US$500 million through the exercise (Berger, 2000).

There appears to be significant gains in productivity materializing from the integration of ICT into the supply chain. These gains are manifested in shortened order-delivery cycle, improved real-time tracking of goods through the supply line, cost reduction, and a better competitive edge for the supply chain participants. As suggested by Earl (1989), ICT can be deployed as a strategic weapon to obtain a competitive edge, improve productivity and performance, and better manage and organize new businesses (Earl, 1989). Accordingly, the researcher suggested the utilization of ICT in strategic and managerial activities rather than in day to day operations. In contrast, the study by Bulmer and Brewer (2000) demonstrates that the full potential of ICT in integrating the operations in the supply chain has yet to

be fully exploited; therefore, it is too premature to dismiss its importance in this area.

In recent years, a number of major construction organisations have embarked on the implementation of ICT integration systems, such as the enterprise resource planning (ERP) system, to better integrate various business functions and resources (Chung et al., 2008). This is evident from the high investments made by these companies in these systems (Wei and Chen, 2008). Nonetheless, the use of ICT systems in the construction supply chain is not without its own set of problems. In fact, due to unique set of conditions and the temporary nature of project participant relationship, it presents challenges that are different from those encountered in manufacturing and other sectors.

Even though there are many ICT system solutions developed to support the needs of the construction industry supply chain, it is an arduous task to actually identify systems that truly manage to address specific industry issues and yield the expected results (Egan, 1998). Some construction companies that have attempted to introduce ICT systems to manage their supply chains have in fact failed (Yang et al., 2007). Studies on ERP system implementation, for instance, show that the success rate is only at 25%, similar to the failure rate, while partial success and outright failure make up the remainder 50% (Kozak-Holland, 2007).

This paper aims to review the success of previous ICT systems implementation in engendering integration and collaboration in the construction supply chain, as well as identify barriers encountered during their implementation. It is the hope of this paper that it will shed new light on the role of ICT system integration in the construction supply chain. In the next sub-section, the most crucial use of ICT systems in construction supply chain management is discussed in depth.

THE USE OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) SYSTEM IN CONSTRUCTION SUPPLY CHAIN MANAGEMENT

As alluded to earlier, ICT system solutions are used in the supply chain to support the business processes, in areas that include transaction processing, partners' coordination and collaboration, and decision making. For the purpose of this review, only systems that integrate with other disciplines and functions in the entire construction PLC are considered. Standalone functional oriented systems that have little direct bearing on construction supply chain management are excluded.

The discussion on these systems is broken into two parts; firstly, a critical review of past literature on different systems used in the construction supply chain, and secondly, a review of the barriers encountered in the implementation of each of the systems. The subsequent section delves into the first part.

Different construction supply chain management system applications

The different construction supply chain management system applications extracted from previous literature (2000-2009) are:

Enterprise resource planning (ERP) system

ERP system appears to be first system to be applied to manage construction supply chain. Its purpose is to integrate all departmental and functional information flows across the company onto a single computer system that caters to all the management needs of the enterprise. With the installation of additional features in the latest version of the ERP software, external suppliers and customers are roped in as part of the chain that the system manages. The research by Gattiker et al. (2007) proves that ERP yields benefits in the form of increased efficiency, quality, productivity and profitability.

Radio frequency identification (RFID) system

Used extensively in the retail industry, this system eliminates manual data entry by using transponders and readers to automatically capture data. It allows the information to flow real time from various sources. RFID tags are used to identify and track products along the retail supply chain (Domdouzisa et al., 2007). The RFID system is another application that has a great potential for use in the construction industry.

E-business

E-Business is a common supply chain application in many industries. According to Elliman and Orange (2000), e-business encompasses business activities that embrace relationships with clients, contractors, suppliers, installers, designers and other partners, in addition to service infrastructure, multiparty, and multidisciplinary (business-to-business) transactions.

According to Lee and Whang (2001), the benefits of embracing ICT in developing e-business solutions to support supply chain activities are apparent. This is especially true in the case of reduction of transaction costs and improved communications. Furthermore, as many researchers agree, there would be greater collaboration between various supply chain parties, including suppliers (Wagner et al., 2003; Kong and Love, 2001). Members in the supply chain can therefore, take full advantage of the e-business process to facilitate work along the project cycle. E-Business is equipped with different communication functionalities that can be harnessed to improve the performance of members in the

supply chain in terms of quality, time and cost. These include business-to-business (B2B), business-to-administrator (B2A), and consumer-to-administrator (C2A) functionalities. Among the sub-systems of e-business that have gained wide popularity are e-procurement and e-tendering.

E-procurement: Dolmetsch et al. (2000) refer to e-procurement as management of supply chains in the procurement of indirect goods that is based on internet information systems and e-marketing. There had been numerous research findings that vouch for the potential benefits of using e-procurement in supply chain, such as that by Puschmann and Alt (2005). E-procurement enables companies to decentralize operational procurement processes and centralize strategic procurement processes. Consequently, the e-procurement system makes supply chains visible.

E-tendering: E-tendering works incredibly well in the construction supply chain. It integrates every process and component of the entire construction tendering supply chain onto an electronic medium. According to Booty (2004), e-tendering reduces bid costs and bureaucracy, as well as offers opportunities for greater clarification of information.

In the United Kingdom, the national e-procurement project highlights the approximate outstanding savings of £8 million per annum within local authorities by using e-tendering (Robert, 2004). Besides, Booty (2004) reveals that a company can stand to save £1500 per tender in paper and administration costs, and a reduced overall spending against the budget by as much as 20%. Based on these and other findings, e-tendering has been regarded as more cost effective than the traditional method, in addition to being time-saving.

Web portal

Another application used in construction supply chain management is the web portal. Companies are increasingly taking advantage of the internet and IT to create a virtual e-chain to communicate and collaborate with supply chain participants (Manthou, 2004). Web services in the portal have emerged as a promising approach to connect and aggregate distributed web applications and information sources (Cheng et al., 2008). Through the web portal, supply chain members can have a single point access to information and applications regardless of location or storage mechanism.

One example of a web portal was developed by Cheng et al. (2008). Known as SC collaborator system, it is able to support supply chain collaboration among project participants and achieve interoperability among organisations in the network. The system also supports communication channels among participants.

Web-based document management system (WBDMS)

The WBDMS provides a centralised, reliable and readily accessible means of transmitting and storing information over the life cycle of the supply chain. With the ability to modify documents to suit various decision requirements and 'what-ifs', the system has proven to be of tremendous help. It adds value not only to internal performance of an organisation but also to the entire supply chain (Nitithamayong and Skibniewski's, 2004) This can be appreciated in the study by Forcada et al. (2007).

Mobile wireless technology

Logistics is a vital component in the construction supply chain. Hence, the use of mobile wireless technologies has contributed significantly to the logistics part of this chain. Effective logistics system can ensure delivery of the right products and services to the correct players at the right time and at minimum cost. As postulated by Bassi and Parand (2002), the advancement of ICT and wireless technologies in the global market has prompted most construction companies to deploy them in supply chain management strategies to seek better output.

Virtual reality (VR)

VR is another construction supply chain application. VR is being used by professional project teams and supply chains to visualize and manage engineering and design data. The study by Whyte (2003) discovers that major businesses that drive the use of VR seek to simulate dynamic operation, coordinate detail design, schedule construction, support interactions with supply chain members, demonstrate technical competence through visualization of previous work, and review designs.

Roles of information and communication technology (ICT) systems and barriers to their Implementation in construction supply chain

From a rigorous review of extant literature, the authors of this paper were able to identify the roles played by various ICT systems in managing the construction industry supply chain. Concurrent to this, the attendant difficulties and barriers to their implementation were also noted. Table 1 summarizes the major findings of this study.

DISCUSSION

The ICT systems used in managing the construction

Table 1. A Summary of literature review on roles of information and communication technology **(**ICT) systems and barriers to their implementation in the construction supply chain.

Type of system	Role of ICT system	Barrier to implementation
Enterprise system		
i. -Metacom6 (ERP system) -Ban ERP system (commercial package) (Voordijk et al., 2003)	-To integrate information systems of various functions in organization.	-System requires high intra-organizational IT maturity. -Temporary and multiple nature of organisational structure. -Network stability and centralised coordination.
ii. Construction enterprise resource planning system (CERP) (Shi and Halpin, 2003)	-To support project management functions.	-Need to standardise the project management process. -Need to reengineer the business practices. -Knowledge capability. -Interaction between human and system solution on decision making -Level of automation.
RFID technology / wireless technology		
i. Automatic digitalized rebar design system (GS BAS) (Chiang, 2008)	For communication and transferring of information between supply chain participants.	Not reported.
ii. Resource management in civil construction using RFID technologies (Kim et al., 2009)	Managing resources in scattered locations and in a real-time manner.	Need appropriate IT infrastructure.
iii. RFID technology (Angeles, 2005)	Facilitate inter-organizational e-commerce (logistics operation)	IT infrastructure (refers to system capability and data management)
E-business		
i. E-commerce (system for construction material procurement, COME) (Kong and Love, 2001)	Managing information of material procurement processes.	Recognized quantifiable methods to measure and quantify time and cost benefit of using System.
ii. E-procurement (electronic purchasing agent (EPA) for material procurement) (Hadikusomo et al., 2003, 2005)	Standardize methods and substandard purchasing procurement practices.	-System inter-operability and system compatibility. -System security. -Server and database (unsuitable for SMEs that do not have own server and database).
iii. E-tendering National e-tendering imperative (NeTI), Malaysia CIDB, Malaysia (2006)	Managing tendering system processes.	An ongoing project.
iv. E-tender system Queensland department of public works/services (Kajewski, 2001)	Managing building tender/ offer processes	-System security. -System networking. -People issue (refers to education and training). -Legal and contractual issues.

Table 1. Contd.

Web portal / web-based		
i. Online remote construction management system (ORCM) (Queensland department of main roads) (Thorpe, 2003)	Centralise project information	-ORCM suitable for complex and large projects but not for small projects with straightforward communication. -IT infrastructure (refers to networking, hardware and software compatibility). -Legal recognition of electronic communication. -Cultural issue. -Investment cost. -Training.
ii. Malaysian construction industry portal (www.ciportal.com.my) CIDB and E-Construct Service (2006)	-One stop centre for knowledge sharing for industry players. -As mediator for collaboration and discussion amongst players.	Not reported.
iii. A portal-based web service (SC collaborator system) (Cheng et al., 2008)	-Platform for individual and organization to collaborate and share information. -Accessible, scalable and interoperable solution -Facilitates integration and collaboration -Establishes relationship among participants.	-Security issue and access control capability for user.
iv. Web-based document management system (Forcada et al., 2007)	-Integration and inter-operability of document management system. -Information exchange through life cycle project.	-Requires standardisation of document processes. -Immaturity of IT knowledge and training.
v. E-logistics (Tiago et al., 2007)	-Information exchange. -Improve communication.	Not reported.
vi. Intelligent wireless web (IWW service logistic supply chain) (Omar and Ballal, 2009)	Manage construction logistics information.	-Requires change to work culture (technological conservatism in construction organizations) -Knowledgeable worker and training. -Top management commitment. -Government initiative.
e. Virtual reality (VR) system		
i. Virtual For Design and Construction (Li et al., 2008)	-To support project teams on construction planning in virtual environment.	-Low adoption of VR amongst contractor -Misunderstanding of VR and perception VR as only an animation tool.

supply chain are primarily focused on integrating all the supply chain participants and enhancing the level of collaboration among them. As revealed by Fabbe-Costes and Jahre (2008), the integration and collaboration spans the flow of resources, the processes and activities, the technologies and systems, and the structures and organizations.

The RFID technology, for instance, is capable of integrating the flow of resources from scattered locations in real-time visibility. It also facilitates communication and

the transferring of information between the designer, the manufacturer, the logistics provider and the end-user. By using this system, an organisation can reduce production loss, construction duration, unnecessary relocation and movement, and material inventory (Chiang, 2008). In the case of the e-business application, it is able to open up channels of communication among the participants. For example, manufacturers of materials can easily have access to contractors and even clients (Elliman and Orange, 2000).

The ICT systems used in construction supply chain are of two kinds; the first being inter-organisational systems (referring to RFID technology, e-business and web-based systems), and the second being functional management information systems including enterprise systems (referring to ERP system and VR). Both types of ICT systems are capable of managerial and operational activities, which are the core activities in construction supply chain management (Turban et al., 2008).

From the review of existing literature on ICT systems used in the construction supply chain, it is apparent that the major obstacle to the effective deployment these systems are IT infrastructure related problems. Several studies (Bryrd and Turner, 2000; Ducan, 1995; Robertson and Sribar, 2002; Schalken et al., 2005) have broadly classified IT infrastructure into two main categories: technical and human infrastructures. Technical infrastructure refers to hardware, software, network, telecommunications, applications and tangible IT resources, whereas human infrastructure refers to the knowledge and skills required to manage IT resources within an organization.

As evident from Table 1, this study finds that the barriers to effective system implementation in the construction supply chain follow very much the two categorizations mentioned above. In terms of technical barriers, several issues were uncovered. These relate to network stability, the need for standardization of process, level of automation, internet connection, system capabilities, system user interface, server, system database, system compatibility and high investment cost. In contrast, human infrastructure barriers include knowledge capabilities, interaction between system solution and human knowledge on decision making, immaturity of ICT knowledge, and training. These barriers cause most of the failures of ICT systems implementation as reported by many researchers (Davies, 2008; Gichoya, 2005; Hartmanna, 2009).

Hence, they should be highlighted for the benefit of construction firms that wish to implement the mentioned systems. The manufacturing industry has been active in identifying implementation barriers to the use of systems as an integral part of its supply chain management (Al-Mudimigh et al., 2004). It is high time that the construction industry follows suit. To succeed in supply chain management, it is instrumental to realize the potential barriers so that implementation strategies can be devised appropriately (Elmuti, 2002).

CONCLUSION AND FURTHER RESEARCH

ICT systems are perceived by the academia and industry practitioners alike as a key driver for many process improvements in the construction industry. However, there is a dearth of information on the roles of systems in managing its supply chain and the barriers encountered in the implementation of these systems. This paper is a humble attempt at filling this gap. Through an extensive review of extant literature on the subject, this study hopes to uncover useful information that can further help the industry to improve its use of system solutions in managing its supply chain. The major findings of this study are as tabulated in Table 1. It is pertinent to note that this study is by no means comprehensive. There are other aspects that need to be further researched in order to facilitate the smooth implementation of systems as a strategy to manage the industry's supply chains. One of the areas that need to be looked into is the capability of IT infrastructure to support the implementation of e-business in the construction industry. Adequate IT infrastructure is a pre-requisite for effective execution of business activities (Xianfeng et al., 2008). Hence, participants in the supply chain need to build their IT infrastructure capability in order to derive tangible benefits from the systems implementation. The lessons that can be gained from this future study can guide policy makers to improve ICT systems integration in the construction supply chain.

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