Integrated IT Systems for Construction Site Management

By

Yong Liang

The thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy
At The Hong Kong Polytechnic University

Supervisor: Professor Heng Li

Department of Building and Real Estate

The Hong Kong Polytechnic University

2006

CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written nor material which has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

(Signed)

Liang Yong (Name of student)

PUBLICATIONS ARISING FROM THE THESIS

Journal papers

Liang Y, Li H, Chen Z, and Kong C W (2005) Application of integrated GPS & GIS technology for reducing construction waste and improving construction efficiency. *Automation in Construction.* **14**(3), pp.323-331.

Kong C W, Li H, **Liang Y**, Hung T, Anumbra C and Chen Z (2005) Web Services Enhanced Interoperable Construction Products Catalogue. *Automation in Construction.* **14**(3), pp.343-352.

Liang Y Cao Y, and Li H (2005) Using Engineering Drawing Interpretation For Automatic Detection Of Version Information In CADD Engineering Drawing. *Automation in Construction.* **14**(3), pp.361-368.

ACKNOWLEDGEMENTS

The research is supported by a postgraduate studentship provided by The Hong Kong Polytechnic University. I would like to express my gratitude to Professor Heng Li, my chief supervisor, for his enthusiasm, his kind advice, numerous constructive comments and the revisions of my writings. I am deeply grateful to his guidance, support and friendship, and I am deeply impressed by his rigorous scholarship and his scholarly research works. The research cannot be finished without his huge support and contribution.

Abstract

This study presents a framework for integrating various information technologies (IT) to support the project procurement process. The project procurement process studied in this research includes the construction material procurement and site production management. Six kinds of innovative construction IT applications are addressed in this thesis, including E-Commerce System for procurement management, Smart card and Barcode System for identification of workers, materials and equipments, Construction Project Information System for documentary management, Design Information System for design and surveying, and E-Tendering System for project tendering, and GPS&GIS based technology for waste reduction in construction. The focus of this research is to identify and evaluate a framework to provide an overall support the information flow of the project procurement process. In developing such a framework, the study adopts the following principle: the strength of a chain is dependent on its weakest element. In other words, this study advocates that stand-alone applications of IT to the project procurement process are not efficient and effective. Instead, there is a need for an overall framework to guide the application of IT to support the project procurement process.

The uniqueness of the thesis is reflected at two aspects. First, it identified and evaluated a number of information technologies that can be applied to support various stages of the project procurement process. Second, the study developed a framework which can provide some guidance for applying IT in supporting project procurement process. The major contribution of this thesis is that it presents an explorative study of integrating GIS and GPS for off-site construction material transportation. Within this study, the GPS and GIS integrated construction M&E management system enables managers from both headquarters and construction sites to get real-time information to control cargoes on the road to sites and to reduce the waste generation on sites.

Contents

List of Tables

List of Figures

List of Abbreviations

AGC	Associated General Contractors of America, USA
ANP	Analytic Network Process
ASCE	American Society of Civil Engineers, USA
Auto-ID	Automatic identification
B2A	Business-to-Administration
B2B	Business-to-Business
B2C	Business-to-Consumer
CAD	Computer-Aided Design
CII	Construction Industry Institute
CIRIA	Construction Industry Research and Information Association, UK
CM	Construction Management
CPM	Construction Project Management
C2A	Consumer to Administration
DBMS	Database Management Systems
DERT	Department of the Environment, Transport and the Regions, UK
E-Commerce	Electronic Commerce
EDI	Electronic Data Interchange
EFT	Electronic Funds Transfer
EIT	Egan Improvement Target
ENR	Engineering News Record
GDCPP	Generic Design and Construction Process Protocol
GIS	Geographical Information System
HTML	Hypertext Markup Language
ICT	Information and Communication Technology
IRC	The Institute for Research in Construction, Canada
IRP	Incentive Reward Program
IT	Information Technology
PM	Project Management
R&D	Research and Development
RFID	Radio Frequency Identification
VAN	Value Added Network
XML	eXtensible Markup Language

Chapter 1 Introduction

1.1 Introduction

A construction project consists of many processes and necessarily generate a vast amount of information. Despite the fact that some IT based computer systems, such as computer aided design (CAD) systems, are extremely powerful and widely used, and parts and packages of the entire construction process have been supported by various IT solutions, there is still a lack of efforts to integrate and streamline the information flow chain within the construction processes.

The main difficulties of integration are exacerbated by the fragmentation of design and construction information. The drawings are expected to provide the experts from different areas of interest the information they require and serve as the main medium for integration. Despite the fact that computer-aided design (CAD) systems are extremely powerful, they are not being utilised thoroughly in the AEC industry. Specialists in the AEC (Architectural, Engineering and Construction) industry have used today's CAD systems as simply automated drafting tools, thereby automating their own narrow areas of specialisation. Each participant uses unique drafting conventions and their own CAD systems. Information is scattered about the project in an uncontrolled and uncoordinated way, on a variety of information systems and media, so that the design cannot be viewed as a complete entity. Such obstacles to the free flow of information between parties to the construction process lead to data re-entry and the consequent inaccuracies, which prejudice future design 'migration paths' and operational flexibility. These are responsible for many of the quality problems and for adding to the costs of construction projects.

This thesis presents a study in which an integrated IT system for construction project management (IIT-CPM) is developed and tested.

Construction management is a professional service that applies effective management techniques to the design, planning, procurement, and construction of a construction project lifecycle from inception to completion for the purpose of controlling time, cost, quality, safety, healthy and pollution, etc. (CMAA 2003). According to the *PMBOK® Guide* (PMI

2000), there are five process groups in project management, including initiating processes, planning processes, executing processes, controlling processes and closing processes. Despite there are similar kinds of process groups in construction project management, the construction industry has its specific contents of process groups in project management such as the generic design and construction process protocol (GDCPP) on construction projects (Kagioglou *et al.*, 1998), where the processes of construction project management were divided into four broad stages with respective ten phases within them as presented below:

- Pre-project stage:
  - Demonstrating the need
  - Conception of need
  - Outline feasibility
  - Substantive feasibility study and outline financial authority
- Pre-construction stage:
  - Outline conceptual design
  - Full conceptual design
  - Coordinated design, procurement and full financial authority
- Construction stage:
  - Production information
  - Construction
- Post completion stage:
  - Operation and maintenance

On the other hand, the design and construction process was also mapped into eight sub-processes (Activity Zones), including Development, Project, Resource, Design, Production, Facilities, Health & Safety, Statutory & Legal, and Process Management. Although some leading construction enterprises such as Alfred McAlpine, AMEC, BAe, BNFL, CRISP, IAI, Carillion, and Christiani Nielsen, etc. have adopted the GDCPP (Thorpe 2001), the process protocol is still under development so as to consummate its broad feasibility and adoptability in the construction industry. On the other hand, the applications of information technology (IT) in construction project management can only be easily adopted by construction managers or contractors if such applications are developed to deal with management operations in specific processes in construction projects. As a result, this thesis will centre attention on a group of specific process based on the GDCPP in which innovative construction IT applications can be effectively and efficiently applied, a group of corresponding process-oriented IT applications and their integrated solutions in construction project management.

1.2 Innovative construction IT applications

In order to determine the group of specific process where the best IT practice can be applied, the researchers of this thesis conducted a comprehensive literature review on both formal and informal publications and documents from the academia and the industry. It has been observed that while the construction industry is familiar with the use of a few general commercial computer software applications for construction project management such as computer-aided design (CAD) tools, construction estimation tools, and construction scheduling tools etc. (AGC 1996, Tang 2001, and Green 2003), the outputs of academic research for innovative construction IT applications have been on track to raise as shown in Table 1.1 since 1990 when the IT utilisation in the construction industry began to increase significantly (Green 2003).

The researchers of this thesis found that although the five statistic curves in Table 1 show downward tendencies around 1999 which is consistent with NASDAQ Chart at the same period while most contractors are planning to invest in IT regardless of profit, profitable firms more frequently believed that IT yielded a cost and market advantage (AGC 1996), the long-term tendency of innovative construction IT applications is upward and the tendency can thus be approximately quantitatively presented by using the linear model below:

$$NP = 7.20879Y - 14205.28571 \tag{1.1}$$

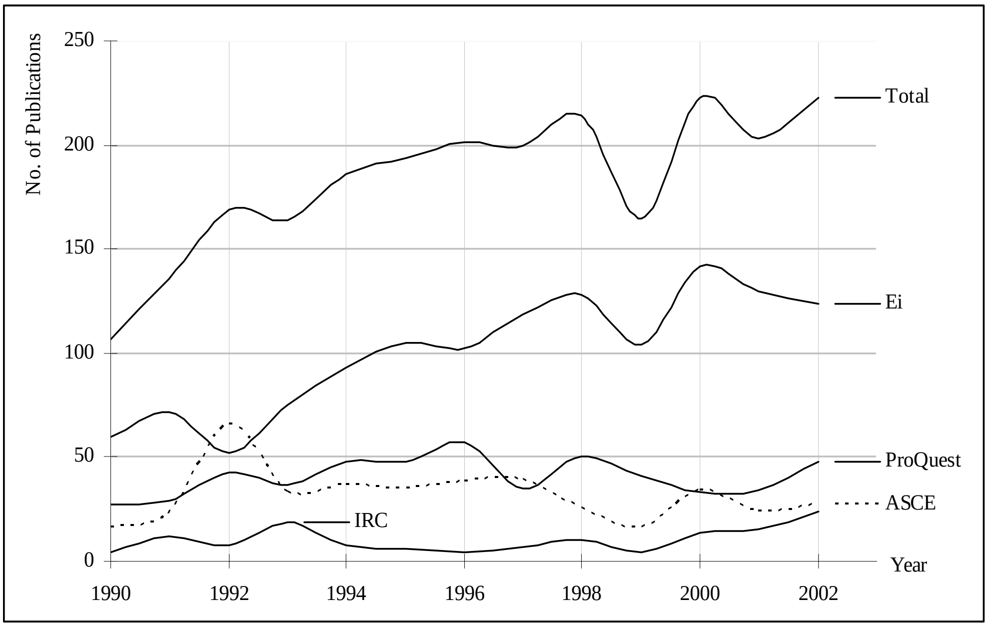
Where the NP represents the total number of publications for innovative construction IT applications, and Y represents the number of Year that is to be examined. According to the statistic result, the total number of publications for innovative construction IT applications is

on track to raise following the increasing order of time, and a high level of consensus exists in the research and development (R&D) of innovative construction IT applications.

Table 1.1: Publications for Innovative Construction IT Applications since 1990

Organization	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003*
ASCE	16	23	66	33	37	35	38	39	26	16	34	24	27	57
EiEV2	60	72	52	75	93	105	102	119	128	104	142	130	124	53
IRC	4	12	8	19	8	6	4	7	10	4	14	15	24	11
PQDD	27	29	43	37	48	48	57	35	50	41	33	34	48	7
Total	107	136	169	164	186	194	201	200	214	165	223	203	223	128

Chart



Note: ASCE- American Society of Civil Engineers, U.S.A.
EiEV2- Engineering Village 2, Elsevier Engineering Information Inc., U.S.A.
IRC- The Institute for Research in Construction, National Research Council, Canada
PQDD- ProQuest Digital Dissertations, UMI (University Microfilms), U.S.A.
2003*- Data collected as of July 2003.

However, factors that inhibit a higher IT take-up in the construction industry have also identified through a number of surveys of the use of IT carried out in many countries for a variety of purposes (Howard, Kiviniemi, and Samuelson 1998). For example, an annual survey of information technology practices in the construction industry recently conducted by ZweigWhite (2002) found that 64% of the 135 firms responding to a 188-item survey in January and February 2002 presented their improvements to communications and connectivity as their biggest IT successes. But 27% presented problems with remote access and communications as their biggest IT failure. In addition, a five-year trend toward more complex office networking was found to continue. Every firm responding had at least one local area network and 94% have at least one leased-line, full-time Internet connection. All but 5% have public Websites. Some 49% presented there were plans to implement a network or intranet. On the other hand, an eight-month research project was conducted in 2000 in order to identify the engines for change to meet the challenges set by C21 (1999) for the construction industry in Singapore to become a world-class industry (Dulaimi, Ling, and Ofori 2001), and the research revealed that the absence of strategic development and utilization of IT was the second major problem faced by the construction industry in Singapore, and thus prevented companies from achieving significant improvements in their activities. According to the results from these surveys, IT could not be developed and utilized to an optimal level due to the perceived high start-up costs involved. This leads to low level of use of IT in the company. Many firms use IT for simple word processing and spread sheet functions, and do not exploit other potential such as for e-commerce, Internet and even email. Construction industry participants also could not use more IT because of the lack of a standardized system of classifying and sharing of information to allow increased usage of IT. As a result, the following major problems exist on the way to successful implementation of IT (Tang 2001):

- lack of local construction based and user-friendly IT applications for conducting effective and efficient construction management,
- absence of reengineering in construction management to widely combine information and communication technologies (ICTs) across disciplines,
- low awareness at management levels of the potential benefits of high-level integrated implementation of IT in construction management,
- high cost on initial development and uncertain return on investment, and
- low IT literacy among construction personnel to initiatively increase use of IT as an integrator in construction management.

1.3 Innovative construction project management using IT

The fact that the implementation of IT did not grow up in step with the upward tendency of the R&D of IT innovation in construction project management indicates that the R&D in construction IT has to work out some cost-benefit, high-efficient, and user-friendly solutions for conducting effective and efficient project management. As a matter of fact, there are many evidences of successful innovative construction IT applications in project management. For example, Thomas and Bone (2000) examined three major infrastructure projects in UK in order to demonstrate how innovation contributed to achieving challenging targets set by Egan (1998) for the construction industry, and they found that the technical innovation through IT adoption is the second most frequently emerged item among fourteen improvement areas in these construction projects. The researchers of this thesis further studied their thesis and found the three innovation themes including supply chain management and partnering, risk and value management, and technical innovation, which were regarded as three areas of innovation in the thesis (Thomas and Bone 2000), can also be used to indicate the degree of adopting IT innovation themes in these construction projects and their potential relations to the Egan improvement targets. As a result, this thesis provides a set of indicators to evaluate various IT applications for innovative construction project management so as to find the best IT solution for contractors at construction planning stage and thus help them to achieve the Egan improvement targets by using the selected IT solution.

Table 1.2 gives a list of selected indicators for innovative construction project management using IT. There are three main kinds of indicators summarized in Table 1.2, including Egan improvement targets, Project management innovation themes, and Academic responses to industry challenges.

In order to use these indicators to evaluate and select the best IT solutions for project management in the appointed construction project, the author of this thesis further developed a decision-making model in which all these indicators are integrated into an analytic network process (ANP) and the ANP model is described in Figure 1.1.

Table 1.2: Indicators for innovative construction project management using IT

(EIT) Egan improvement targets (Egan 1998, and Thomas and Bone 2000)	
(CPC) Capital cost (-10%)	(PDB) Predictability (+20%)
(CTT) Construction time (-10%)	(PDT) Productivity (+10%)
(DFT) Defects (-20%)	(TOP) Turnover & Profits (+10%)
(ADT) Accidents (-20%)	
Project Management Innovation themes (Thomas and Bone 2000)	
(SCAMP) Supply chain management and partnering	
(TIP) The initiative process	(COC) Co-ordinating committee
(DRP) Dispute resolution procedure	(FAE) Facilitator & monitoring and performance evaluation
(INC) Internal communications	(CAP) Contractual and Partnering innovation
(DAC) Design and construct contract	(PCA) Preferred contractor approach
(RIVLM) Risk and value management	
(DSM) Disposal of surplus material on site	(MIG) Minimization of import of granular materials
(ALD) Alternative designs	(SCL) Stabilized capping layer
(SWM) Site-won materials	(STD) Structural redesign
(RIT) Reducing imported topsoil	(MMF) Mammal fencing
(TENIT) Technical innovation	
(EDM) Electronic data management	(OBM) Observational method
(AMS) Modern asset management strategy	(EMP) Environmental programme

(ARTIC) Academic responses to industry challenges (Luck, McGeorge, and Betts 1997)
(IC1) To place greater emphasis on the assessment of the impact of buildings on the environment.
(IC2) To translate the client's expectations from the initial briefing process into a specification of services.
(IC3) To place more importance on IT support to construction site processes.
(IC4) To integrate the processes of design, construction and operation of buildings.
(IC5) To capture final built form upon completion using built drawings or building model.
(IC6) To place greater emphasis on post occupancy evaluation of the interaction of people and buildings.
(IC7) To conduct supply-chain management of contractors, sub-contractors, specialists and suppliers.
(IC8) To evaluate the constructability of design.
(IC9) To systematically study buildings in use for information about performance and guidelines.
(IC10) To use green design information.
(IC11) To link up the flow of information amongst project participants.
(IC12) To enable performance prediction tools as an integrated suite of tools with appropriate user interfaces.

IT Innovation themes (Luck, McGeorge, and Betts 1997)			
(ITIV) Visualisation			
(VBM) Buildability model	(V3D) 3D model	(VVR) Virtual Reality	(VMM) Multi-media
(VVV) Visualisation	(VRM) VRML	(VQT) QuickTime VR	(VCD) CAD
(ITII) Intelligence			
(IKB) Knowledge-base system	(IDM) Data mining	(ICR) Case-based reasoning	(IEM) Energy modeling

(IKM) Knowledge management		(IKE) Knowledge elicitation	(IIM) Intelligent material
(ITIC) Communication			
(CDC) Data communication	(CBC) Bar-coding	(CSC) Site communication	(CSW) CSCW
(CWC) Wireless communication	(CIN) Internet	(CAI) Auto identification	(CEC) Ecommerce
(COD) Online product database	(CIA) Intranet	(CPJ) Paperless jobsite	
(CAC) Automated data capture	(CED) EDI	(CES) Exchange standards	

(ITIT) Integration

(IDB) Database	(IID) Integrated database	(IDW) Data warehousing
(IOO) Object-oriented programming	(IOM) Object modeling	(IOL) Object libraries
(IIM) Information management	(ICE) Concurrent engineering	(IPM) Product modeling
(IDI) Data integration standards		

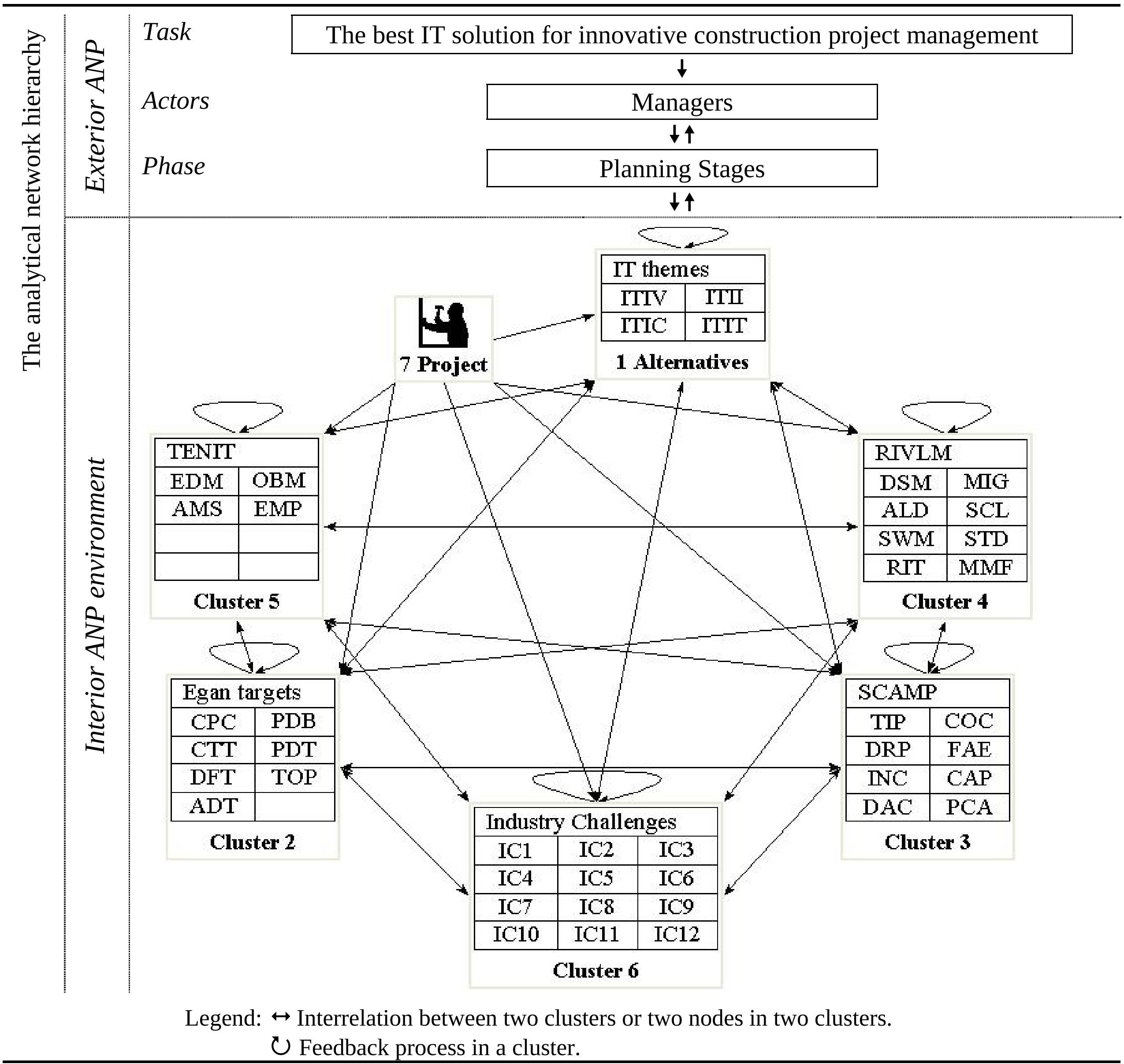


Figure 1.1: A decision-making model for construction IT applications evaluation

The ANP decision-making model for construction IT applications evaluation to an appointed construction project includes exterior environment and internal environment. In the exterior

ANP environment, the downward arrow indicates the process of transferring data required by the ANP, the upward arrow indicates the process of feedback with evaluation results from the ANP, and the feedback process (loop) between the exterior environment and the internal environment indicates a circulating pipe for environmental priority evaluation of alternative IT solutions for innovative construction project management.

In the internal ANP environment, connections among seven clusters and 50 nodes are modeled by two-way and looped arrows to describe the interdependences existed. The seven clusters are IT Solution Alternatives (Cluster 1), Egan improvement targets (Cluster 2), Supply chain management and partnering (Cluster 3), Risk and value management (Cluster 4), Technical innovation (Cluster 5), Academic responses to industry challenges (Cluster 6) and Project character (Cluster 7). In correspondence with the seven clusters, there are 50 nodes including four nodes in Cluster 1, seven nodes in Cluster 2, eight nodes in Cluster 3, eight nodes in Cluster 4, four nodes in Cluster 5, twelve nodes in Cluster 6, and seven nodes in Cluster 7. Concerning the interdependences between any two clusters and any two nodes, the ANP model structured here is a simple ANP model containing feedback and self-loops among the clusters, but with no control model, because there is an implicit control criterion with respect to which all judgments (paired comparisons) are made in this model: IT solution for innovative construction project management. For example, when comparing the node Disposal of surplus material on site (DSM) in cluster Risk and value management (Cluster 4) with node Internal communications (INC) in cluster Supply chain management and partnering (Cluster 3), the latter is obviously more important for adopting IT solutions, and similarly the relative importance of the clusters can be decided under the same implicational criteria. Table 1.2 lists the indicators used in constructing the ANP model and the corresponding references from which the indicator is retrieved.

There are 39 kinds of IT applications involved in the four IT themes summarized in Table 1.2, although the ANP model conducted in Figure 1.1 does not provide an alternative cluster for all of them and considers their four IT belongingness only, specific IT solutions such as e-commerce system and project management information system can also be evaluated as specified items in the alternative cluster in the ANP model. In other words, the ANP model conducted in Figure 1.1 can be generally employed to evaluate any IT solution of the same kind. With the help of the ANP model developed in this research under a supposed environment of current construction projects, the researchers of this thesis further studied on all publications mentioned in Table 1.1 and found that the potential qualified IT applications in the innovative construction project management exist in the following three areas:

- Procurement: E-Commerce System
- Automatic Identification: Barcode and Radio Frequency Identification
- Documentary: Construction Project Information System

As a result, this thesis will then follow up both technical and economic aspects in the implementation of the four kinds of IT applications in order to help contractors to achieve high effectiveness and efficiency in innovative construction project management.

1.4 Research Methodology

In this study, various IT systems were examined in a view to develop a conceptual framework that is generally applicable to the construction industry. The IT systems under study were jointly developed and implemented by the Hong Kong Polytechnic University and a major construction company in Hong Kong. Through thorough literature review, case studies, questionnaire survey and interviews, improvements to the current IT systems were proposed and the conceptual framework was developed.

1.5 Organization of the Thesis

There are five chapters in this thesis. These chapters are organized according to their relationships with the objectives of the research. To start with the introduction to the research and development (R&D) in the construction industry, the need for integrative IT solutions in construction project management is presented based on statistical data and a decision-making model on adoption and implementation of IT applications in construction enterprises. After an evaluation for the potential qualified IT applications in the innovative construction project management, three types of practical IT applications, including Procurement (E-Commerce System), Automatic Identification (Barcode and Radio Frequency Identification (RFID)), and Documentary (Construction Project Information System), are elaborated individually. Finally, a conclusion is given for the selection of innovative IT application s in construction project management. The overall structure of the thesis and its relationship with the project procurement process are illustrated in Figure 1.2.

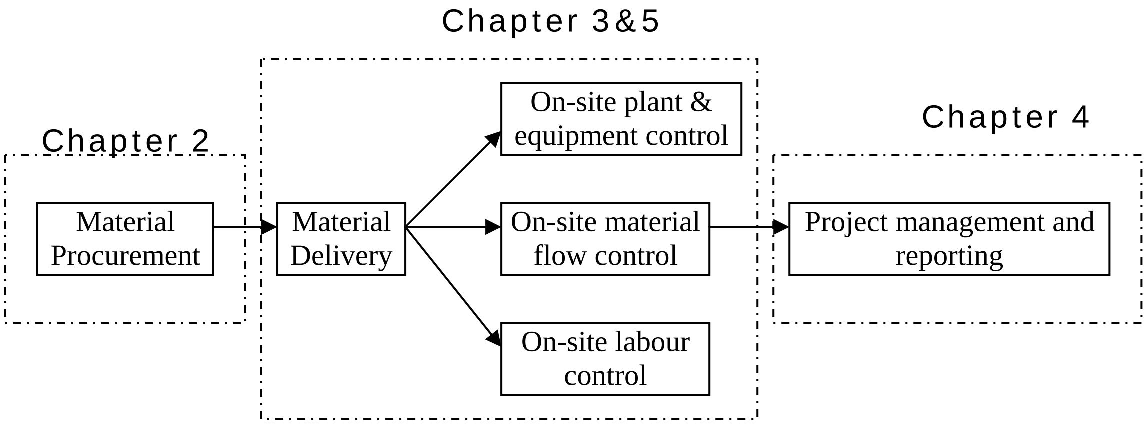


Figure 1.2: Organizational Structure of the thesis

1.5.1 Chapter 2 E-Commerce System

Electronic commerce (E-Commerce) systems for trading construction materials have been developed and deployed in these few years. These systems utilize Internet and Web technologies to integrate and streamline business processes, and to provide an expanded marketplace for the buyers, sellers and agents to trade construction materials. On one hand E-Commerce allows buyers to purchase cheaper products with a variety of choices due to the more transparent market and elimination of middlemen, on the other hand E-Commerce can cut administration cost as business processes are streamlined and many paperwork tasks reduced.

This chapter firstly introduces the traditional construction material procurement functions and process, and points out its problems in the area of information flow and limitations of existing practice. The evolution of E-Commerce is then introduced, with discussion on its network infrastructures, communication protocols and programming languages. The classification of, and the linkage of different trading parties in business models of E-Commerce are also presented. Security, which is one of the major obstacles to adopting E-Commerce, is then discussed. The security issues include authentication, data integrity, confidentiality, non-repudiation and access control. Risks of an insecure E-Commerce system are introduced, which include threat of false or malicious Web sites, theft of customer data, customer impersonation, and denial of service attacks.

One important element of E-Commerce system – Internet-based electronic product catalog (IEPC), is discussed in this chapter. The evolution of IEPC, its elements and functions, and its benefits are introduced. Another element of E-Commerce system, which is beneficial to construction material trading, is geographical information system (GIS). GIS is the unique information system that maintains, manages, integrates and analyses, spatial information of different types and scales. The major functions of GIS are spatial data management and integration, spatial data query and analysis, network analysis, and spatial data visualization. Applying GIS in E-Commerce can facilitate calculation of materials transportation distance, time and cost. Also GIS provides useful functions for analysing trading pattern in different geographic locations.

The later part of this chapter gives some example of existing E-Commerce system for construction materials trading and points out existing limitations of these systems. One of the limitations is the lack of a standard for representing materials information. The issues on information standardization are discussed and a concept of information standardization for enabling information sharing between different E-Commerce systems is introduced. Two technologies, mobile agents and Web services, for enabling information sharing are presented in the last part of this chapter.

1.5.2 Chapter 3 Automatic Identification

This chapter introduces the technique of Automatic Identification (Auto-ID) and two types of its applications to the construction industry, including barcode technique and Radio Frequency Identification (RFID) technique. Although the RFID technique is advanced than the barcode technique, it is suspended in this thesis due to the feasibility of the RFID system adopted in the construction project management at present; however, the advantage of the RFID technique indicates its potential adoption in construction project management. As a result, the author of this thesis recommend that the barcode technique and its application system, such as material and equipment management system be adopted in construction project management.

1.5.3 Chapter 4 Construction Project Information System

The construction industry is an information rich industry, both in terms of the information it generates and exchanges among participants, as well as the information it absorbs from outside sources. The effective management and transfer of information are crucially important to the successful completion of construction projects. Construction projects necessarily involve more organizations coming from different geographical locations. The task of coordination and information sharing/exchange therefore becomes very challenging. Construction project management systems have been used by many practitioners to due with these information related issues. These systems streamline information flow and integrate many business processes.

This chapter evaluates the current practice of the construction industry and identifies its problems relating to information manipulation. Some business model of construction project management systems are discussed, which include Intranet-based and Internet-based models. Specifically, this chapter uses VHBuild™ system, a project management system developed by construction IT firm in Hong Kong, as an example to illustrate functions of project management system that address business needs of the construction industry. The later part of this chapter presents findings of a questionnaire survey on evaluating barriers and benefits of adopting construction project management system.

1.5.4 Chapter 5 Application of integrated GPS & GIS technology for reducing construction waste and improving construction efficiency

This chapter presents a study on applying an integrated GPS & GIS technology to the reduction of construction waste. During the study, a prototype study is developed from automatic data capture system such as the barcoding system for construction Material and Equipment (M&E) management onsite, whilst the integrated GPS & GIS technology is combined to the M&E system based on the Wide Area Network (WAN). Then, a case study is conducted to demonstrate the deployment of the system. Experimental results indicate that the proposed system can minimise the amount of onsite material wastage.

1.5.5 Chapter 6 Conclusions and Recommendations

Based on the literature review related to the research and development of IT in the construction industry, and the evaluation result from the ANP decision-making model, this thesis recommend three potential qualified IT applications in the innovative construction project management, including e-commence system for procurement of construction material and equipment, bar-coding system for construction material and equipment management on site, and construction project management system for documentary management. Conclusion and recommendations have been presented in this chapter that the three IT applications above are the primary means of IT solutions for innovative construction project management.

Chapter 2: Development of Construction E-Commerce System

2.1 Introduction

Electronic Commerce (E-Commerce) has the ability to conduct business via electronic networks such as the Internet and the World Wide Web. Although E-Commerce is based on the principles of Electronic Data Interchange (EDI) it goes far beyond EDI in that it aims at supporting the complete supply chain of a construction project, including the information stage (electronic marketing, networking), the negotiation stage (electronic markets), the fulfillment stage (order process, electronic payment) and the satisfaction stage (after sales support).

Emphasis these days is on business-to-business (B2B) E-Commerce applications: taking orders, scheduling shipments, providing customer service and so on. Construction organizations conducting their business using E-Commerce typically work together in a seamless supply chain as a single unit using various telecommunications and advanced information technologies so as to increase the effectiveness of their business relationships between trading partners. The use of such telecommunications and technologies is set to revolutionize the way that organizations operate in the next millennium. Thus, many construction organizations are now reviewing their information systems so that they can exploit recent technological developments and therefore enable improved organizational competitiveness through E-Commerce.

Many believe that E-Commerce can provide a win-win situation for both suppliers and buyers, as E-Commerce can provide an expanded marketplace within which buyers and suppliers can communicate directly with each other. Online construction trading markets are not limited by the physical limitations of store spaces and can carry a much larger variety of products and different styles and sizes. At the same time, buyers can search through a wide range of products with low transaction costs at any time convenient to them. More importantly, the direct communication between buyers and suppliers will cut off the multiple layers of middlemen between suppliers and buyers. These middlemen take commissions and fees from both buyers and suppliers. Use of E-Commerce will therefore directly benefit the buyers so they can purchase cheaper products with a variety of choices (Bakos 1991).

2.2 The Traditional Construction Material Procurement Process

2.2.1 Purchasing and Procurement Objectives

Purchasing is responsible for establishing the flow of materials into the firm, following-up with supplier, and expediting delivery. Procurement is part of the purchasing functions, which is concerned with establishing material specifications, selecting suppliers and products, determining price and negotiating with suppliers. The main concerns of material procurement are the provision of the right materials at the right time, in the right place and to an agreed budget such that progress on site is uninterrupted (Canter 1993). Procurement shares the same objectives as purchasing which are:

- Obtaining goods and services of the required quantity and quality,
- Obtaining goods and services at the lowest cost,
- Ensuring the best possible service and prompt delivery by the supplier, and
- Developing and maintaining good supplier relations and developing potential suppliers.

2.2.2 Purchasing and Procurement Cycle

Generally the purchasing cycle in most of the businesses consists of the following steps:

Step 1. Receiving and analyzing purchase requisitions.

Step 2. Selecting suppliers. This step involves finding potential suppliers, issuing requests for quotations, receiving and analyzing quotations, and selecting the right supplier.

Step 3. Determining the right price.

Step 4. Issuing purchase orders.

Step 5. Following-up to assure prompt delivery.

Step 6. Receiving and accepting goods.

Step 7. Approving supplier’s invoice for payment.

Material procurement includes step 1 to step 4. Firstly the purchasing department receives purchase requisitions from the department that require materials. According to the material specifications the purchaser looks for suppliers that provide those materials. For those materials that have been purchased before, there is usually a list of approved suppliers for the purchaser to select. In case there is no relevant supplier information the purchaser will look for information from catalog, trade journal, or directory. Although catalogs may contain prices of materials, it is usually desirable to issue a request for quotation especially when performing bulk purchase. The request for quotation is a written inquiry that is sent to enough suppliers to be sure competitive and reliable quotations are received. After the suppliers have completed and returned the quotations to the purchaser, the quotations are analyzed for price, materials' compliance to specifications, terms and conditions of sale, delivery, and payment terms. The purchaser will then determine the prices of the selected suppliers. Price negotiation with the suppliers is necessary when quoted price is not satisfactory. After arriving a suitable price the purchaser will issue a purchase order to the selected supplier. Copies of purchase order are usually sent to other department like accounting, receiving and the department that issue the purchase requisition.

2.2.3 Material Purchasing Process in Construction Firm

The purchasing process in construction firm is different from other business firms. In a construction firm the purchasing process splits into two stages: the tender stage and the post-contract stage. Figure 2.1 depicts the activities and their sequence in a typical material procurement process. In the tender stage, a contractor starts estimating after receiving tender documents from client and send out enquires to suppliers. When quotes are received from suppliers, contractor will select the best quotes and complete the tender documents. If contract is awarded in the later stage, the purchasing process will be repeated from step 2, which is selection of suppliers. This is because market condition may change from time to time. Sometimes quotes received from suppliers are no longer valid at the post-contract stage. Even quotes are still valid at the post-contract stage the purchaser should send request for quotation to the suppliers again to get the most updated market price. Once a suitable supplier has been selected, the next step in the purchasing process is to raise and issue a purchase order to the supplier, which will constitute a legal contract when the supplier accepts or acknowledges receipt of the order. In effect the order becomes a written commitment to accept and pay for goods under an agreed set of terms and conditions. Orders will then be tracked until materials are received and checked on site.

Tender Stage	**Post-contract Stage**
Tender Receipt	Contract Awarded
↓	↓
Estimating	Re-enquiry and Negotiation
↓	↓
Look for Suitable Materials	Supplier Selection
↓	↓
Send out Enquires to Suppliers	Order Placed
↓	↓
Quotes Received	Progress Measured
↓	↓
Analyses	Records Kept
↓	
Selection of Best Quotes	
↓	
Tender Prepared and Submitted	

Figure 2.1: Typical material purchasing sequence

2.2.4 Information Flow in the Material Procurement Process

From the requisition of quotations at the tender stage to the actual receipt of materials and signing invoices, different paper-based documents are produced, copied, passed and referenced by different groups of participants in the traditional material purchasing process. During the tender stage the estimating teams of contractors obtain construction materials information from physical catalogs of suppliers. Based on these catalogs they compare and select suppliers and send enquiries to and receive quotations from the selected suppliers.

Figure 2.2 shows a typical paper-based document system of a purchasing function during the post-contract stage of a project. In a typical paper-based document system, the site office prepares two copies for the requisition of materials. One copy is sent to the buying department and one copy is filed. The buying department then prepares four copies of the purchase order. One copy is sent to the selected supplier and the site office, and both the accounts department and the buying department keep the remaining copies for their records. The site office will receive invoice issued by the supplier when materials arrive on site. The invoice will be compared with the purchase order by the buying department and after confirmation, be passed to the accounts department to issue payment (Calvert 1995).

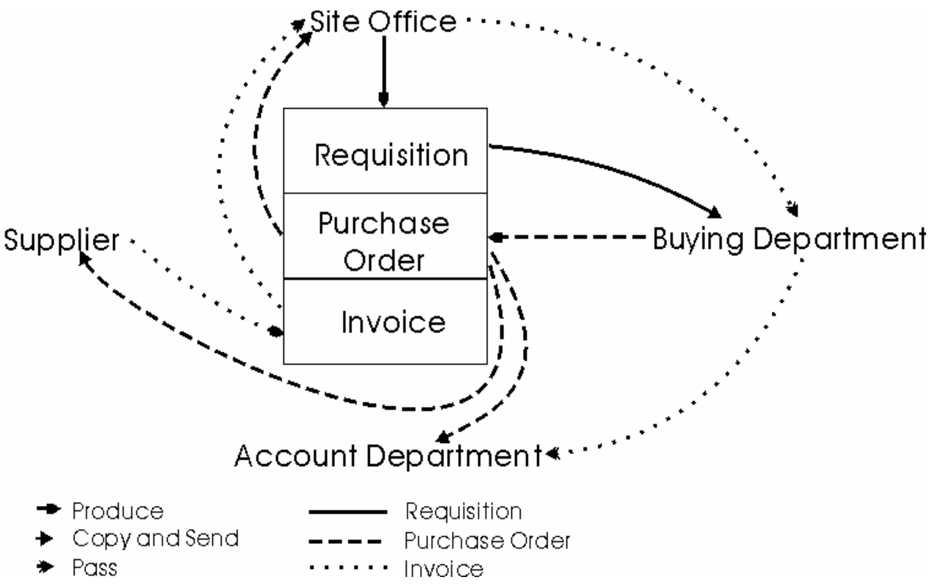


Figure 2.2: Paperwork required in the purchasing system

2.2.5 Limitations of Traditional Material Procurement Process

It is proffered that the traditional material procurement process has the following limitations. First, this process has specific business hours and can only work with suppliers within a defined geographical region. In addition, the traditional process can only collect limited amount of information about the suppliers and their products through the collection of physical catalogs. Physical catalogs are cumbersome to use, and require large storage areas. They also become dated very quickly, and make searching and comparison of prices and quality a nebulous task. These disadvantages make it increasingly difficult for contractors to stay abreast of market conditions and thus select the most suitable materials and suppliers for a given project.

Additionally, the paper-based transaction system that is commonly used within the realm of the traditional process of material procurement is time-consuming (and thus non-value adding). As mentioned above, copies of different documents are produced manually and are used by different parties in the material procurement process. The probability of error increases as information is transcribed from one document to another. Although paper documents can be re-typed into a computer-based environment, data entry of document information requires multiple transcriptions of the information. Consequently, such process can result in the introduction of additional errors to the system. Furthermore, the paper-based system is also dependent on ensuring that all appropriate departments obtain copies of the documents necessary to do their job. If a small percentage of those documents are lost or misplaced, there can be gaps in the system and orders may go unfulfilled.

2.3 E-commerce Application

E-commerce is the conducting of business communication and transactions over networks and through computers (Haynes 1995). Narrowly, E-commerce is used to refer to the buying and selling of products and services, and the transfer of funds, through public or private digital networks. E-commerce includes all types of inter-company and intra-company business interactions, transactions, functions processes (such as marketing, advertising, sales, support, recruiting, research & development, administration, and corporate communication) that enable commerce by utilizing technologies such as e-mail, electronic data interchange (EDI), electronic funds transfer (EFT), the World Wide Web, video conferencing, electronic forums and bulletin boards, and distributed databases.

There are two types of technology necessary for supporting E-commerce: network infrastructure and applications. At the core of an E-commerce environment lies the digital network, which interconnects all parties together so that they can communicate and transact business with one another. Until recently, EDI has been the predominant form of E-commerce. EDI transactions are transported in two primary ways: direct dial-ups and value added networks (VANs). Direct dial-ups offer point-to-point connection, and allow a company to periodically pick up EDI data from or deposit EDI data into its trading partners' computers. By using a VAN, a company can multicast the same EDI transaction to multiple business partners. The VAN is responsible for holding the data in the receiving company's mailbox until the data is picked up. Studies have shown that using EDI for linking with business partners in the supply chain can help reduce processing, cycle-time, improve accuracy, and create strategic value (Mukhopadhyay 1998). However EDI fails to be widely adopted due to its high setting up and running cost, and its technological limitations. The cost of subscribing to a third party VAN and related services is still high. The high cost is only justifiable for those large firms that often have large volume and batch oriented transactions with their trading partners. Also when implementing EDI firms have to follow the message standard and integrate EDI into their existing legacy applications. It is expensive and lengthy to do these setting up works. It has been postulated that the text-based and preordained formats of existing EDI standards are too rigid and outdated, given the current dynamics of business environment and marketplace which demands non-text capability, flexibility and customizable business logic (Marchal *et al*. 1998). The cost of implementing EDI for the construction firms is especially high due to the fragmented and one-off nature of construction project. Contractors usually have to deal with a large number of suppliers, which are invariably different for each project. The costs associated with EDI can be further exacerbated when sources of construction materials are geographically remote.

The limitations and barriers in EDI are overcome by the introduction of Internet and Web technology. The Internet is the world's largest and fastest growing collection of public networks. In year 2000, there were 336 million Internet users. Catalyzed by the Internet, the worldwide electronic business increased to US$31.2 billion from US$11.2 billion in 1998 (Robert and Toby 2001). Internet is now the only viable network infrastructure that can serve as the backbone of a global electronic marketplace, connecting together businesses both large and small, and foreign and domestic. Network infrastructure is now not the barrier of E-commerce. The remaining area of concern is whether application software can fulfill the requirement of E-commerce.

The computing industry divides E-commerce application software into two components: front-end and back-end. Front-end application produces interactive interface for the users. The enabling technology is a Web browser that can compile standard Hypertext Markup Language (HTML) and those cross-platform languages like JavaScript. Common elements of front-end interface include text, graphic, button, form, hyperlink, table, etc. Back-end application often involves interfacing with existing databases and applications in the server.

2.3.1 Electronic Links between Trading Parties in E-commerce Environment

An E-commerce system for assisting product procurement creates electronic links between suppliers, buyers and agents (Sirinivasan 1994, Wang and Seidmann 1995, and Choudhury and Konsynski 1998). These links can be organized in different ways. As shown in Figure 3.1, buyers and suppliers can either form direct connections without any intermediary (a), with intermediaries (b), or acquire the products through electronic markets (c) (Strader and Shaw 1997). These three types of connections allow product information of suppliers and the request for product by buyers to be accessed through a network, which provides a platform for buying and selling of products electronically.

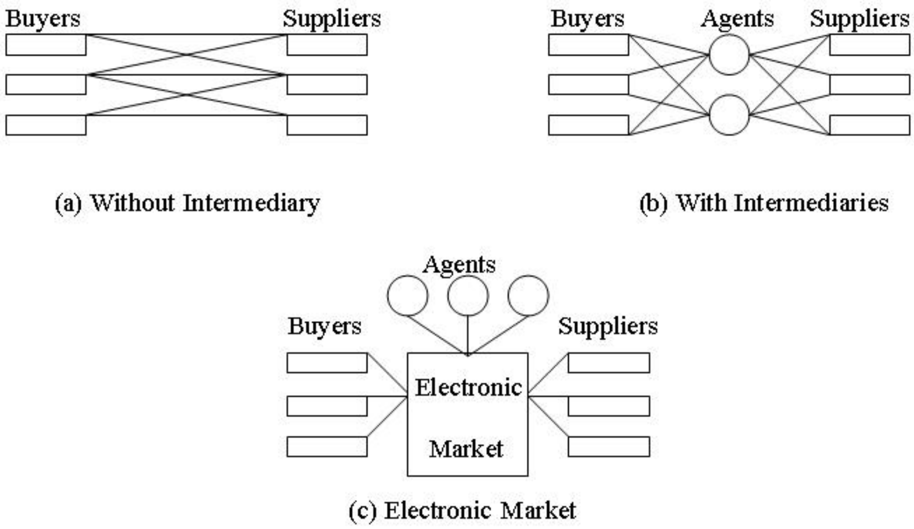


Figure 2.3: Three types of buyer-supplier communication structure

From Figure 2.3, it can be seen that type (a) provides direct linkage between suppliers and buyers, which supports bargaining and bidding trading situations, but it is difficult to support other trading situations. Type (b) allows buyers to search and compare more products from the intermediary's platform and facilitates trading situations such as auctions and contracts based trading, but the intermediary becomes an unavoidable part of the supply chain which makes it inconvenient to have direct communications between buyers and suppliers. Therefore, type (b) cannot support bargaining and bidding trading situations. The electronic market in type (c) provides a platform for the suppliers to put their product information online. Buyers can easily search and compare products of a pool of suppliers, and to contact suppliers directly. If necessary, buyers can also invite the agents to undertake certain tasks required in order to complete a transaction. Thus, type (c) has the most flexibility and functionality to support all the four trading situations encountered in construction material trading. The E-commerce business model presented in the following section is therefore based on the type (c).

2.3.2 Business Models of E-commerce

There are currently three types of classification on business models of E-commerce: 1) by types of order and delivery, 2) by types of trading parties, and 3) by types of business activities. These three types of classification will be discussed in the following sections.

2.3.2.1 Classification by Types of Order and Delivery

There are four types of business models by this classification: 1) off-line order off-line delivery, 2) on-line order off-line delivery, 3) on-line order on-line delivery, and 4) off-line order on-line delivery (Liang & Huang 2000). For the off-line order, off-line delivery type, information of products is available from the Internet, but both ordering and delivery are executed off-line. The on-line order, off-line delivery type of E-commerce system provides on-line information of products and also allows users to make orders on-line. Once ordered, the product will be delivered off-line. In an on-line order, on-line delivery E-commerce system, information of products is provided on-line, and users can order the products in the system. Once ordered, the products or services will be delivered to the customer on-line. The off-line order, on-line delivery type of E-commerce requires customers to make orders in the traditional way, but the products or services is delivered through the Internet.

2.3.2.2 Classification by Types of Trading Parties

According to the European Commission (1999), E-commerce can be divided into four distinct categories: 1) B2B, 2) business-to-consumer (B2C), 3) business-to-administration (B2A), and 4) consumer-to-administration (C2A). B2B E-commerce is the carrying out of business transaction between two businesses parties using electronic means. An example is a contractor ordering materials from a supplier's website and paying online. Business to consumer E-commerce is the trading of consumer products online. Consumers can buy products from the manufacturers directly from the website. This can cut off middleman and thus allowing business firms to get higher profits while charging lower price. An example is a customer buying computer directly from Dell's website (http://www.dell.com). The business to administrator type covers transactions between companies and government organizations. For example in Hong Kong, the government takes the initiative to promote B2A E-commerce. An example is the Electronic Tendering System implemented by the Government Suppliers Department of Hong Kong SAR (http://www.ets.com.hk). This tendering system allows registered suppliers to search tender notice and to submit tender offer. The last type, consumer to administrator, covers transactions between citizens and government. The Hong Kong government has already implemented a comprehensive electronic payment system for the citizens to pay different fees online using credit card account (http://www.esd.gov.hk). The available services include payment for vehicle license, education loan, business registration, examination fee, etc.

2.3.2.3 Classification by Types of Business

A classification of business models of E-commerce by types of business is presented by Laudon and Laudon (2000). This classification introduces nine category of business models, namely Virtual Storefront, Market Place Concentrator, Information Brokers, Transaction Brokers, electronic clearinghouses, reverse Auction, Digital Product Delivery, Content Provider, and On-line Service Provider. The description and examples of these categories are presented in Table 2.1.

Table 2.1: Internet Business Models (Laudon & Laudon 2000)

Category	**Description**	**Examples**
Virtual Storefront	Sells physical goods or services on-line instead of through a physical storefront or retail outlet. Delivery of nondigital goods and services takes place through traditional means.	Amazon.com Virtual Vineyards Security First Network Bank
Market Place Concentrator	Concentrates information about products and services from multiple providers at one central point. Purchasers can search, comparison-shop, and sometimes complete the sales transaction.	Internet Mall DealerNet Industrial Marketplace InsureMarket
Information Brokers	Provide product, pricing and availability information. Some facilitate transactions, but their main value is the information they provide.	PartNet Travelocity Auto-by-Tel
Transaction Brokers	Buyers can view rates and terms, but the primary business activity is to complete the transaction.	E*Trade Ameritrade
Electronic Clearinghouses	Provide auction-like settings for products here price and availability are constantly changing, sometimes in response to customer actions.	Bid.com OnSale
Reverse Auction	Consumers submit a bid to multiple sellers to buy goods or services at a buyer-specified price.	Priceline.com
Digital Product Delivery	Sells and delivers software, multimedia, and other digital products over the Internet.	Build-c-Card PhotoDisc SonicNet
Content Provider	Creates revenue by providing content. The customer may pay to access the content, or revenue may be generated by selling advertising space or by having advertisers pay for placement in an organised listing in a searchable database.	Wall Street Journal Interactive Quote.com Tripod
On-line Service Provider	Provides service and support for hardware and software users	Cyber Media Tune Up.com

2.3.3 Benefits of E-commerce

Web technology overcomes the system incompatibility problem of EDI by encapsulating enterprise systems as object components, made accessible by standardized interfaces, and standardized protocol for transmitting documents between these components through the

Internet (Gek 2000). The Internet provides a transparent means of communication between the buyers and suppliers. Users only need to know the address of the other party. Even though the Internet is a complicated network of switches, communication lines, software, and equipment, it is of no concern to users. The key to this simplicity is the separation of the various user organizations into islands with their own Internet networks connected to the islands by a common protocol (Andreoli *et al.* 1997). The standardization of network communication technology has significantly reduced the cost for installing a Web site and the unit cost for information transmission also becomes virtually negligible. From the technological point of view, Web technology should be able to provide a cheap and efficient means for the contractors and suppliers to trade construction materials online. Generally a company applying Internet and Web-based E-commerce has the following benefits (Greenstein and Feinman 2000):

- Internet and Web-based E-commerce is more affordable than traditional EDI;
- Internet and Web-based E-commerce allows more business partners to be reached than with traditional EDI;
- Internet and Web-based E-commerce can reach a more geographically dispersed customer base;
- Procurement processing costs can be lowered;
- Cost of purchases can be lowered;
- Reductions in inventories;
- Shorter cycle times;
- Better customer services; and
- Lower sales and marketing costs.

Procurement cost can be lowered by traditional EDI systems by consolidating purchases, developing relationships with key suppliers, negotiating volume discounts, and greater integration of the manufacturing process. Internet E-commerce offers additional benefits and potential for cost reductions over traditional EDI. Procurement costs can be lowered for all companies, regardless of size, due to the increased ability to transact electronically with one another. In the suppliers' side, a reduction in inventory is desirable because of the associated reductions in storage, handling, insurance, and administrative costs. E-commerce can help firms to more optimally order the inventories by electronically linking suppliers and purchasers together and allowing them to share updated production forecasts and projected inventory levels in order to allow both parties to collaboratively fine-tune their production and delivery schedules. Customer services can be enhanced using Internet-based E-commerce by helping the customer to access information before, during and after the sale. Before the sale is made, customers can electronically retrieve product specifications, quantity, and pricing information. During the products fulfillment cycle, customers can electronically check on the status of the order. After sales services that can be provided to customers include electronic notification of returned items and the ability to download and print the necessary documentation and shipping labels to return an item for servicing. Generally benefits that consumers may expect to receive are:

- Increased choice of vendors and products;
- Convenience from shopping at home or office;
- Greater amounts of information that can be accessed on demand;
- More competitive prices and increased price comparison capabilities; and
- Greater customization in the delivery of services.

2.3.4 Security Issues in E-commerce Development

One of the Internet's greatest benefits, increased connectivity, is also at the root of a business' greatest fear. The Internet was not created with the intention of using it as a communications network to conduct sensitive transactions securely and reliably. A public network by its nature is susceptible to information being viewed, copied, or altered while in route to its final destination. Consumers have long heard horror stories about hackers intercepting credit card data on the Internet. This fear consumers have about secure payment processing has been a major stumbling block for Internet commerce thus far. With the use of encryption technology and digital signatures, consumers can be assured that the risk of credit card details being intercepted are less than the risk many cardholders run today when they hand over their card to a waiter in a restaurant.

Security threats upon information will exist in any networking environment, whether a document is sent over the public Internet or by using a proprietary VAN. However, a large advantage that a VAN has over a public network is an assurance that the data sent over the VAN will not be compromised in any way. Several measures must be taken to increase the security posture of an open network to meet the level of standards that subscribers to a VAN would expect.

2.3.4.1 Security of Data during Transmission

Trading partners subscribing to a VAN and transmitting data over private lines can be relatively comfortable that an EDI document will be routed to its recipient without any modifications. However, this level of assurance is not provided when connecting to the Internet via Internet service provider (ISP). This can be illustrated by performing an Internet network trace. By utilizing program commonly called Traceroute, any Internet user can follow the route traveled by an Internet Protocol (IP) packet from its source to its final destination. This exercise yields some interesting observations. First, the Internet does an efficient job of routing packets to their final destination. Second, between the source and the destination many different intermediate network nodes handle the packet. At any one of these nodes, any individual with a network protocol analyzer, or sniffer, could easily capture, view, or reassemble the packets that make up a data packet. Additionally, a technical glitch occurring at any one of the hops in the route could cause the packet to be dropped or discarded. If the information contained in the packets contains sensitive information, measures must be taken to prevent such threats from occurring when an EDI document is sent over an open network such as the Internet.

2.3.4.2 Audit Trails and Acknowledgements

VAN subscribers have the capability to track an EDI document through the VAN. An example of this involves notifications sent to the trading partner upon the download of the EDI document by the recipient from its VAN mailbox. A second example is a functional acknowledgement sent by a VAN to the sender which indicates the receipt of a transaction by its recipient. Document tracking and functional acknowledgements offered by the TCP/IP protocol suite or supplied by an ISP do not meet the level of service provided by a VAN. This tracking information is very important in designing any on-line application, as well as in meeting the approval of financial auditors and legal counsel.

2.3.4.3 Authentication

The process of determining that a trading partner is indeed who he or she claims to be is called authentication. It eliminates the possibility of spoofing the identity of a trading partner while a document is in transit on a public network, such as the Internet. In the case of a VAN, a trading partner can only send or receive documents after they have been authenticated by the VAN. This process usually consists of the user logging into the network with the appropriate username and password.

2.3.5 Risks of Insecure E-commerce System

Risk can be defined as the possibility of loss or injury or someone or something that creates or suggests a hazard. Losses or injuries on the electronic frontier may occur in many different ways. Data may be stolen, corrupted, misused, altered, or falsely generated. Attacks on hardware may occur that render systems unable to operate properly. Hardware or software may be used without authorization, which may translate into lost revenue or slower response time for authorized users. Programs may be altered to cause systems to perform incorrectly or even to crash. In terms of electronic commerce, risk is viewed as the possibility of loss of confidential data or the destruction, generation, or use of data or programs that physically, mentally, or financially harms another party, as well as the possibility of harm to hardware. This section introduces the issues faced by firms that have connections to the Internet and that use the Internet for electronic commerce.

2.3.5.1 False or Malicious Web Sites

Malicious web sites are typically set up for the purpose of stealing visitors' Ids and passwords, stealing credit card information, spying on a visitor's hard drive, and uploading files from the visitor's hard drive.

2.3.5.2 Theft of Customer Data from Selling Agents and Internet Service Providers

Customers purchasing goods and services on the Internet typically pay with credit cards. This credit card information is stored by the selling agents and ISPs. Unfortunately for the customers, hackers are occasionally successful at breaking into the selling agent's and the ISP's systems and obtaining the customers' credit card data. This risk is comparable if someone uses his/her credit card for any other purpose since corporate database containing non-Internet customer credit card information may also be penetrated and stolen.

2.3.5.3 Customer Impersonation

One risk to the selling agent is that the customer is not the entity they claim to be, also called impersonation. If one can misrepresent himself/herself as a legitimate customer, he/she can order goods and services for a variety of reasons. One reason may be to obtain a free service or product, such as to purchase and download software paid for with a false credit card number. Another reason may be to have goods shipped with no intention to receive or to pay.

2.3.5.4 Denial of Service Attacks

Selling agents, among other web site servers, may be the target of malicious attacks called denial of service attacks. A denial of service attack is used by an individual to destroy, shutdown, or degrade a computer or network resource. The goal of such attacks is to flood the communication ports and memory buffers of the targeted site to prevent the receipt of legitimate messages and service of legitimate requests for connections. The primary loss is down time and the system can usually be easily recovered by rebooting it. For many business on the Internet, however, lost time can mean lost sales and, therefore, lost revenue.

2.3.5.5 Data Theft

Data files such as customer lists and engineering drawings that are stored digitally and connected to public telecommunications lines can potentially be accessed by an unauthorized user without the perpetrator ever having to leave the comfort of home. Furthermore, the perpetrator may be miles or oceans away from which the data is stolen. Additionally, if perpetrators suspect exposure, they can quickly disconnect and likely not be traced. The risks of theft of data can be reduced by preventive techniques such as firewalls and encryption.

2.4 Internet-based Electronic Product Catalog

One important application of electronic commerce which will play a vital role in the emerging global electronic marketplace is the Internet-based electronic product catalog (IEPC). An IEPC is a World Wide Web based application that provides companies with a new channel to market, sell, and support products and services over an open network environment. From the customer's point of view, it offers an alternative means of finding out what product or service is currently available in a given market, who the suppliers of that product or service are, and where and how to get such a product or service. As a new medium,

IEPCs combine many useful features of existing channels, such as the rich content of printed catalogs, the convenience of home shopping, the intimacy of on-site shopping, and the sophisticated searching capability of CD-ROM catalogs. However, the most important characteristic of IEPCs is that they can be seamlessly integrated with other functions of the company and of its business partners. For example, the content of an electronic catalog can be dynamically generated from the company's product database in response to the user's query. Since the company's inventory database can be linked to its supplier's ordering system, the supplier can be automatically alerted to ship any particular product when its inventory level reaches a certain threshold value. When a customer makes a payment through an electronic catalog, the transaction can first be sent electronically to the merchant's bank, which, perhaps through a third-party, transfers funds from the customer's account to the merchant's account. In an electronic environment, the above process is carried out transparently. The electronic catalog serves as a front-end application that provides a uniform interface to the global electronic marketplace. Moreover, it can also serve as a "virtual gateway" to the individual company through which customers gain access to the company's product information, people, and support services, as well as provide feedback about the company's products and services.

2.4.1 Evolution of Product Catalog

IEPCs are transcended from paper-based product catalogs. Paper-based product catalogs contain colorful and structured presentations of products. Over time, product catalogs have changed their styles along with the carrier of information for which they were created. The first type of electronic product catalogs (EPCs) were CD based catalogs. Most of them are still offline catalogs, but compared to their paper-based predecessors, CD based catalogs offer sophisticated search functionalities as well as multimedia product presentation.

IEPCs are an evolved generation of EPCs, which are based on a powerful ubiquitous carrier of information. Based on the features of the Internet, they are online and can seamlessly integrate with other business functions of the company and its business partners. Thus, in comparison with CD based catalogs, they are up-to-date, they allow for dynamic adoption of content presentation according to the needs of buyers and they provide a direct communication channel between the buyers and the sellers.

2.4.2 Elements and Functions of IEPC

Timm and Rosewitz (1998) define IEPC as a system that allows customers to browse through multimedia product representations and to get relevant information concerning the product. Another definition is given by Keller and Genesereth (1997) who see IEPC as the reference for product selection that can assist with source selection and description of terms and conditions. A more comprehensive definition is given by Stanoevska-Slabeva and Schmid (2000): “IEPCs are interactive and multimedia interfaces between buyers and sellers on the Internet, which support product representation, search and classification and have interfaces to other market services as negotiation, ordering, and payment.” The author see IEPC as an interactive front-end interface that provides classified and structured product information, and supports product searching, comparison and evaluation, and may have linkage with other e-commerce services such as bidding, ordering and payment.

Any IEPC contains two constitutional elements: 1) Keywords or abstract references to the available information and 2) detailed information about products in various forms. In an IEPC of construction materials, keywords are usually the product categories. Detailed information includes structured product information, unstructured product information and buyer-generated information. Structured information is stored in relational databases and can easily be offered online with available state-of-the-art databases and online merchant technology (Lincke 1998). The form of the unstructured information varies from documents to complex multimedia data structures (Elsworth and Ellsworth 1995). Buyer-generated information appears in different forms: ratings of products, contributions to discussions, contribution to virtual communities, customer testimonials or comments (Hagel and Armstrong 1997).

IEPC serve as a tool to facilitate efficient search for product offering over the Internet (Kalakota and Whinston 1996, Whinston *et al* 1997). The core functionality of IEPCs is to provide an easy access to product information and selection. As shown in Figure 2.4, there are generally three steps in the online product selection process: product browsing or searching, product evaluation and comparison, and product selection. Each of these steps will be explained in the following sections.

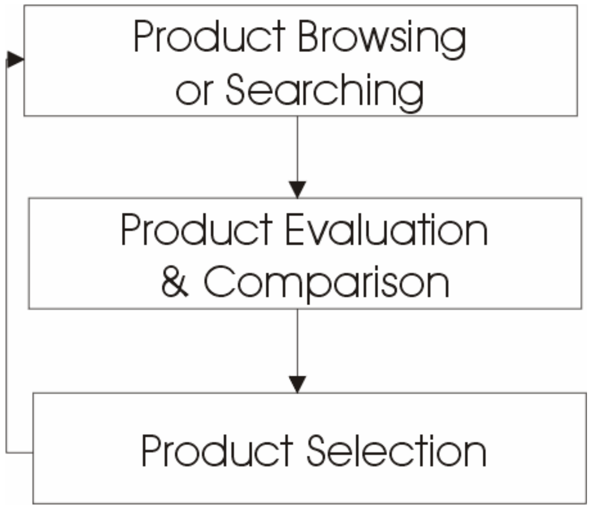


Figure 2.4: Product selection process in IEPC

2.4.2.1 Product Browsing

Buyers access the catalog of a supplier in order to browse through the offered products or to find a specific product they need. During product browsing, the most important function of an IEPC is the establishment of a common understanding between the buyer and the supplier through the offered information. This can be best achieved when all information related to a product is offered at once. Keywords are used as placeholders and representatives for retrievable information. The common understanding usually has to be established on a first compressed abstraction of the other content. For instance, a buyer may need to go through certain levels of keywords of product category before he/she can view the detailed description of a product (Figure 2.5). It would be very helpful to get more information about the meaning of the keywords or about the next level of keywords before selecting.

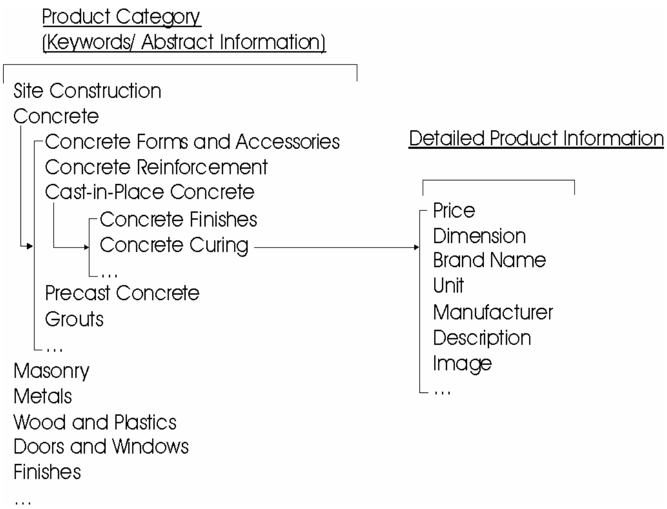


Figure 2.5: Linkage between keywords and detailed description of a product

2.4.2.2 Product Searching

An electronic product catalog can be viewed as a search service operating in a search market to facilitate the process of selection (Whinston *et al.* 1997). Depending on the types and amount of product information provided in IEPCs, the search service can operate sequentially or simultaneously. In the case of searching product on a website of a single supplier, buyers will need to search through different suppliers' sites one by one to compare products. However, in the case of searching product in an electronic market, where products of many different suppliers can be found, buyers can search through different suppliers' products simultaneously. In any case, search technologies in IEPCs allow buyers to engage in a sophisticated and efficient search.

The process of searching is composed of two major sections: collection of query criteria and the actual search operation. In a simple search function, a buyer will only need to enter keywords to query for results. In a more sophisticated search function, apart from query by keywords, a buyer can set query constraints like price range, physical dimension, weight of product, brand name, category, etc. In some more advanced search functions, the query constraints may be entered in more than one step. The constraints entered in the earlier steps will refine the available query criteria in later steps. More sophisticated search functions can yield more accurate and fewer numbers of search results, which can prevent information overload and shorten the buyers' product selection time.

The actual search process passes the query set by the buyers to the search engine. The search process can be as simple as querying a single database, but can also be as complex as querying multiple databases of different electronic market through agent system or mediating ontology (see Figure 2.6).

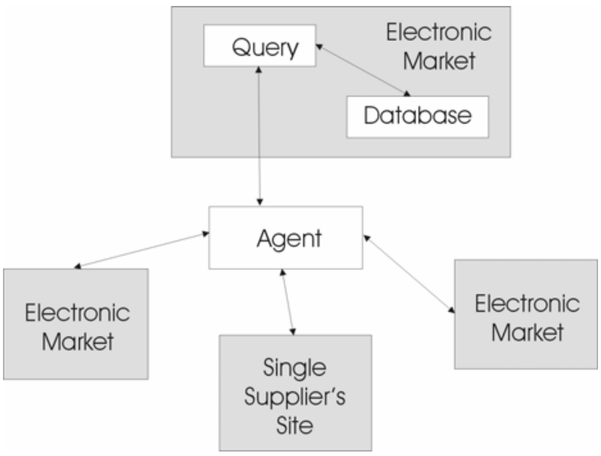


Figure 2.6: Searching mechanism in IEPCs

Querying databases in heterogeneous systems requires the understanding of all systems' database schemas and the ontology used for communication. In any case, all search results matching the query constraints will be passed back to the IEPCs for arranging display to the buyer.

2.4.2.3 Product Evaluation and Comparison

In the product evaluation and comparison stage, IEPCs must enable individual storage of interim results and be able to provide sophisticated functionality for their interactive management and processing to the buyer. It is better to display search results in a single page so that buyers do not need to click back and forth to compare different products. To facilitate evaluation of products, rich content of product information is necessary. Besides text-based product description, multimedia like images, videos and CAD models can be very helpful for buyers to evaluate products. In addition, customer generated information like comments and ranking of products, and external information like news and industrial standard can also assist the buyers in product evaluation.

2.4.2.4 Product Selection

Product selection has two processes: product pre-selection and product reselection. After evaluating and comparing products in the search or browse results, a buyer will need to put his/her pre-selected products in a temporary storage area so that he/she can go on to search for similar or alternative products. The accumulated pre-selected products in temporary storage area should be arranged for easy comparison. Also, functions for changing the elements of the set of pre-selected products should be provided. In addition, transparent interfaces to other e-commerce services like ordering and negotiation must be provided.

2.4.3 Benefits of IEPC

An IEPC allows companies to bypass the need for costly printed catalogs, it is easier to update, and can also be linked directly to the purchase process (Kosiur and David 1997). It provides valuable assistance to a customer during the product identification and evaluation stages because it embodies two major aspects: content description and search interfacing (Whinston *et al.* 1997). It also possesses four important characteristics: interactivity, dynamic updating, hypertextuality, and global presence (Segev *et al.* 1995). All these benefits contribute to lower running cost and attraction of more customers.

2.5 Geographical Information System in E-Commerce

Geographical Information System (GIS) is the unique information system, which maintains, manages, integrates and analyses, location-related (or spatial) information of different types and scales. Successful implementations of GIS are found in many areas, such as civil engineering, transportation, facilities management, urban planning and business analysis. E-commerce system offers a possible solution for direct trading between buyers and suppliers with no restriction on space and time. However, online transaction should not only focus on the flow of business-related information but also effective distribution of goods (Yang *et. al*, 2000). Transportation of goods among different parties must be involved in any kinds of business activities, even in the era of online business. Consequently, cost of transportation is also a critical consideration in E-commerce. Moreover, both regional and local demographic characteristics are important considerations in the successful implementation of the E-commerce system. In this sense, location related, or spatial information plays an essential role in any kinds of business activities, including E-commerce system. GIS is potentially applicable in e-commerce system to manage spatial information, provides an ideal solution to manage costs of transportation and market analysis in the overall E-commerce activities.

2.5.1 Functions of GIS

2.5.1.1 Spatial Data Management and Integration

Figure 2.7 demonstrates a well-known layer-based architecture, which is commonly employed in traditional GIS. Each layer in the GIS denotes a single theme (or fact) in a particular area. Although these layers seem to be separated, they are connected via their common representation framework – a coordinate system. Although GIS closely links to database management systems (DBMS) as general information systems, GIS differs from other information systems with its own data indexing system. Queries in general information system bases on values of stored data, for example, retrieve all suppliers with their annual revenues greater than $1 million. In order to optimise performance of the query, data is usually managed according to their numerical / alphabetical order. GIS, on the other hand, queries base on the locations of the features, for example, retrieve all suppliers locate within 10km from of a city. Data in GIS is managed according to their locations in space, that is, adjacent features in space are stored in near locations in physical storage devices. This approach of data management is unique in GIS and facilitates many types of spatial queries and analyses that are practically impossible in other information systems. Moreover, with this architecture, information about one particular location or area can be easily managed and integrated, even though they are obtained from different disciplinary, different data types and different scales.

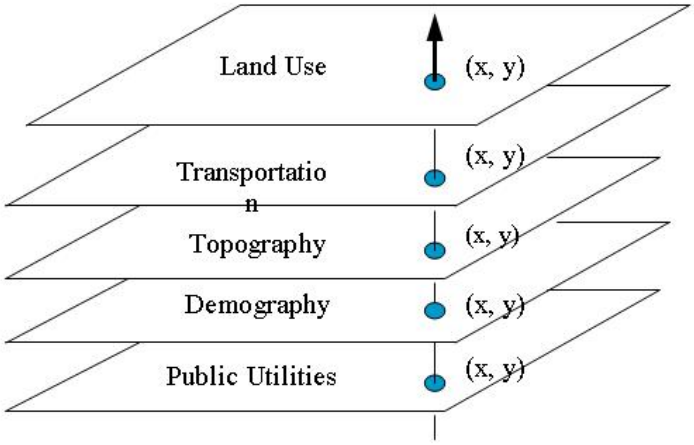


Figure 2.7: Architecture of GIS

2.5.1.2 Spatial Data Query and Analysis

With the architecture mentioned above, GIS is a unique tool from which users are able to ask questions concerning with locations and relationships among locations. Depending on natures of applications, questions to be answered by GIS ranges from simple data query including one data set or data query including multiple data sets based on their spatial relationships, to complex spatial analysis. GIS is usually supplied with built-in functions to perform queries relating to locations, to examine spatial relationships or patterns among multiple spatial data sets, and to combine with external databases and software. Once these functions are put into right places and right applications, GIS not only save time and money in many labor-intensive tasks (e.g. co-relates thousands of paper maps on a light box), but also is a significance tool in supporting decision-making over the space.

2.5.1.3 Network Analysis

Network can be effectively represented in the location-based architecture of GIS. Network is usually defined as a set of connected linear segments. Lines that compose the network are arcs and the intersections that connect arcs are nodes. Network is essential to represent many natural and cultural phenomena in the real world, e.g. stream network, street network, bus routes system and highway system. A commonly asked question about the network is: What is the optimal way to transport resources from one location to another location in the network? GIS can be used to assist the decision making process over the network. Among the different kinds of network analyses, finding the shortest path is the almost fundamental and significant one. This is because solutions of the shortest path analyses are usually applied to higher-level or complex analysis.

Dijkstra's algorithm is the most well-known approach to calculate the shortest path between two point in the network (Dijkstra, 1959). The algorithm computes firstly, shortest paths from the given starting node to all other nodes in the network. For the network shown in Figure 2.7a, node *a* is the starting node. With distances of the arcs, it is known that nodes *b* and *d* are nearest to *a* and shortest paths from *a* to *b* and *d* are arc *ab* and *ad* respectively. Figure 2.7b shows the tree of paths in Figure 2.7a. The tree starts from *a*. Since the nodes *b* and *d* are the immediate neighbours of *a*, arcs *ad* and *ab* are added as first level leafs of the tree. The search is now performed for nodes *b* and *d*. At node *d*, nodes *a*, *b*, and *e* are the immediate neighbours of node *d*, and at node *b*, nodes *d*, *e* and *c* are the immediate neighbours of node *b*. Arcs *ab* will not be added to the tree, since the arc has been recorded already. Consequently, arcs *de* and *db* are added as leafs of *ad*. For leafs of arcs *ab*, *bd* will not be added since this has already been a leaf of arc *ad*. If arc *be* is added, there are two possible paths from *e* to *a*, those are *e-b-a* and *e-d-a*. This is known that the path is shorter when this passes though node *d*, so *be* will not be added as a leaf of *ab*. Eventually, only *bc* is added. Now, nodes *e* and *c* are undergone similar search methods, arcs *ec* and *ef* are added. Arcs *ce* is duplicated. Arc *cf* gives another path *f-c-b-a*, which is longer than the path *f-e-d-a* and therefore, *cf* is not added. Eventually, the tree shown in Figure 2.7b is completed.

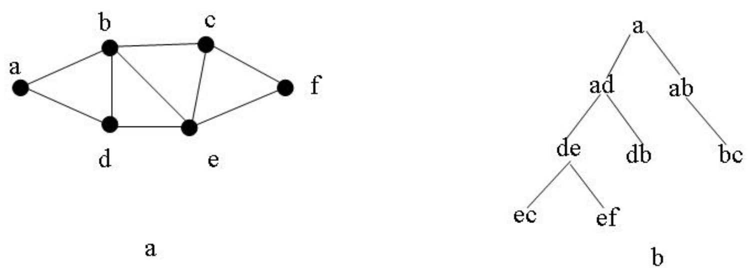


Figure 2.7: a. A simple network; b. tree structure of shortest path

From Figure 2.7b, shortest paths form node a to all other nodes in the network can be traced. For the shortest path from node *a* to node *f* as an example, at the bottom of the tree, this is known that immediate neighbor of *f* is *e*, and neighbor of *e* is *d*, and the neighbor of *d* is *a*, therefore, the shortest path from node *a* to node *f* is *a-d-e-f*.

Here are some examples of the questions concerning network analysis:

- Where are the suppliers of Cement <u>*within*</u> Guangdong province of China?
- Where are the suppliers of Door <u>*near*</u> to my construction site?

– What is the shortest route and best transportation method from supplier A to buyer B and what is the cost of transportation?

2.5.1.4 Spatial Data Visualization

Another important application of GIS is to present data in form of maps automatically. It is known that about 80% of all data are related to locations, hence most data can be analyzed and viewed spatially (www.gis.com). Actually in many cases, map-based presentation of these data is much informative than other formats of presentation, such as table or charts. For example, map-based presentation (Figure 2.9) is more appropriate than text-based presentation for census information (Figure 2.8). GIS usually provides various cartographic functions, such as automatic symbolization based on values of data, automatic text placement, contouring or surface fitting. Some advance GISs even provide three-dimensional mapping ability for multiple-dimensional data.

Apart from mapping a single status of feature at space, GIS can map changes in space as well (www.gis.com). Representation of changes in space is valuable in predicting future conditions and in deciding further actions. GIS maps change by showing where and how feature moves/changes over a period of time. Another approach is to map the statuses before and after an action in order to examine impact of the action.

ArcView GIS Version 3.1

File Edit Table Field Window Help

0 of Select All ted

Attributes of Hked

Shape	Area	Perimeter	Hked#	Hked-i
Polygon	167768937.03606	117533.67316	2	0
Polygon	2476012.69710	17950.59642	3	0
Polygon	40579.62470	853.66604	4	0
Polygon	158062.34265	1652.73700	5	0
Polygon	909356.85795	6353.54956	6	0
Polygon	2135727.65220	11465.23904	7	0
Polygon	94332081.04675	83066.68449	8	0
Polygon	468477.75850	3142.70967	9	0
Polygon	105747102.69076	67564.01247	10	0
Polygon	1691134.67110	7401.03987	11	0
Polygon	45289.49095	1104.59999	12	0
Polygon	196320194.56680	206658.47530	13	0
Polygon	39574.96750	793.61401	14	0
Polygon	518961.25430	3377.25635	15	0
Polygon	92818801.52592	59617.02426	16	0
Polygon	36345880.77963	43534.93844	17	0
Polygon	50311277.71227	42521.33264	18	0
Polygon	375967.30335	4147.94010	19	0

Figure 2.8a: Presenting data in text-based format

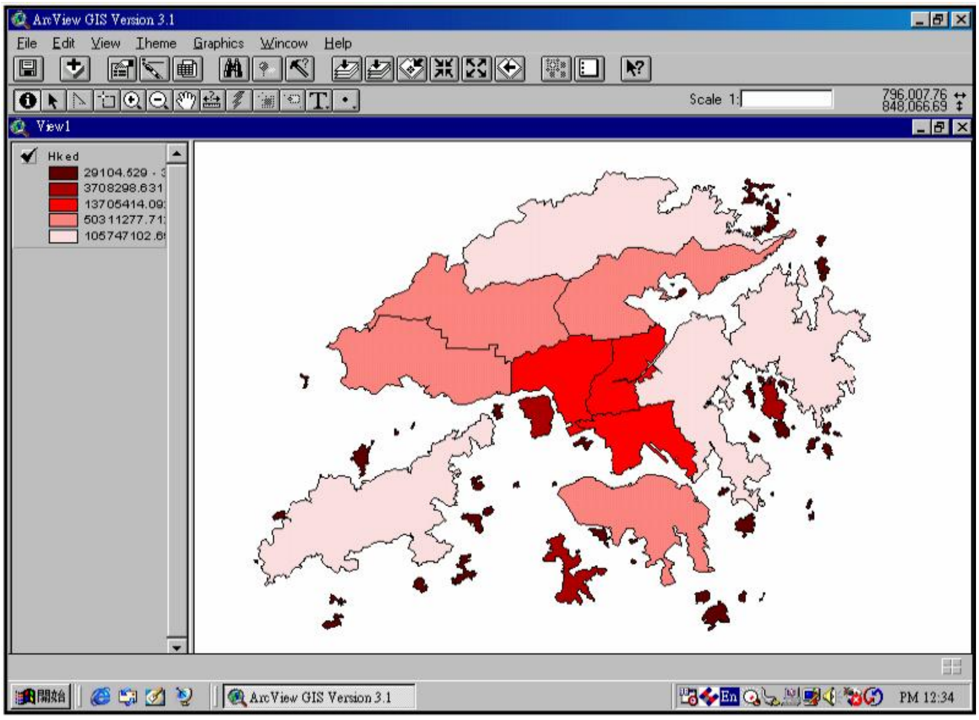


Figure 2.8b: Visualising data using GIS

2.5.2 Roles of Geographical Information and Its Service in E-commerce

Conceptually, the electronic trading process itself is not bounded by the geographical locations of both buyers and suppliers. The system should open for any buyers and supplier in the construction industry all over the world. However, in the industry, buyers consider cost of transportation as one of the deterministic factors in choosing their suppliers. A large percentage of the overall expenditure of the purchase is spent on the cost of transportation. In this sense, geographical location is the only data that provides information about transportation cost. Most importantly, in the platform of electronic market, buyers have relatively less knowledge about suppliers then in the conventional trading process. Apart from the descriptive information of suppliers provided by the system, geographical locations of the suppliers give the buyers some implicit information about the suppliers and qualities of their material. From the suppliers' point of view, the Internet offers opportunity to invest anywhere in the world. However, before an investment is made, economic characteristics of a particular region, for example the rate of establishing new apartments, must have to be carefully considered. Geographical information is a valuable and, many times the only source to compare and to analyze business environments of different regions. Three kinds of geographic information services offered by Web-based GIS in E-commerce applications will be introduced in the following sections.

2.5.2.1 Publishing Geographical Data on the Web

The most foundational use of Web-based GIS in supporting the electronic market system is to provide geographical data associated with suppliers and materials. The underlying idea of the electronic market is to provide a platform from where buyers can find service from a large number of service providers. Since the buyers are not necessary to contact the supplier personal in the on-line ordering system, provision of detail, accurate and up-to-dated information of suppliers and material is the most important consideration. Geographic representation is usually the more expressive way to present a large volume of information, than charts or table. Web-based GIS deliveries geographical data of suppliers to all users of the system, for example, Web-based GIS can provide a directory of supplier and visualizes their locations in form of maps.

2.5.2.2 Spatial Query and Analysis

With the comprehensive geographical database of goods and suppliers, general users without specific training can perform spatial query and analysis in the Web-based GIS. The users can search, for example, the suppliers that provide the most competitive price of material around 5 miles away. Moreover, Web-based GIS allows marketing specialist to see various trading patterns. The specialist can analyze the area in which suppliers of a particular material are highly condensed. On the other hand, suppliers are able to analyze the purchasing behavior of buyers all over the world and to compare the behavior against demographic information in different regions. All results of the analysis can be presented in form of map and included in other documents for further references.

2.5.2.3 Transportation and Logistic

As have been mentioned above, no matter which types of business practice are adopted, the E-commerce system ultimately lead to direct or indirect transportation of goods from suppliers to buyers. Although the principle of online business is to provide a platform from which business activities can be performed without limitations on space and time, costs of physical transferring of goods must be considered. Web-based GIS not only maintains a comprehensive geographical database for transportation networks, but also provides tools to analyse the most cost-effective transportation route to deliveries goods from the suppliers to construction site of the buyer.

2.6 Existing E-commerce Systems for Construction Material Procurement

Numerous E-commerce systems for trading construction materials are developed in Hong Kong, mainland China and Taiwan. Some typical examples are asiamaterials.com, asia-steel.com, assetline.com, bciasia.com, buildgate2000.com, building.com.hk, conmex.com, chinabidding.com.cn, macrobuild.com, skylinehongkong.com, superconstruction.net, and vhcome.com. These systems basically contain two major functions: providing construction material information and facilitating trading transactions. Construction material information, depending on the design of the system, can be provided by material suppliers, agents or manufacturers. Some E-commerce systems are owned and operated by a manufacturer or a supplier and so their material information is very limited. Systems that are owned by an agent company or an application services provider contain more material information provided by different manufacturers and suppliers. In both cases, the process of purchasing material from these E-commerce systems is similar. Buyers firstly log into the system and browse through the material catalog or search for material by specifying search criteria like brand, model, quality, price, etc. When suitable materials are found, buyers can place an order to buy from the suppliers or to select an agent to arrange purchase of all the necessary materials for them. Different E-commerce systems are operated by different types of organizations and they attract different groups of buyers. They specialize in trading materials from suppliers in different regions. Usually a buyer needs to visit more than one of these E-commerce systems in order to find all the necessary construction materials. Figure 2.9 illustrates this situation.

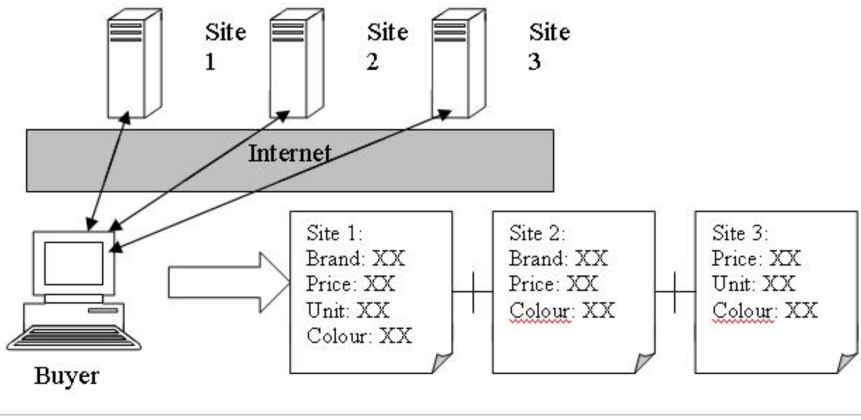


Figure 2.9: Traditional approach to searching and buying a product in E-commerce websites

Different websites have different material searching and display patterns. They also provide different attributes of construction materials. The variety and heterogeneity of different E-commerce websites create problems for the buyers. Finding materials in these sites requires buyers to acquire and maintain a list of web addresses, to interpret and understand the semantics and navigation methods in different sites, and to integrate product information in these sites for evaluation manually. These kinds of material finding job can be time consuming and the buyer is required to keep abreast of new sites. From the point of view of sellers, a closed E-commerce system cannot retrieve information from other systems and thus sellers cannot get comprehensive market information for making decision on production and distribution.

2.7 Information Sharing between E-Commerce Systems

Information is data that have been processed and placed into meaningful context (Zack 1999). In an E-commerce system for construction material trading, information may include material information, supplier information, manufacturer information, buyer information, agent information, and market information like the amount of sales of different materials, buying patterns, buyers' comments on materials and services, etc. Organizations along a supply chain are now linking their information systems together to form inter-organizational system. Inter-organizational systems are networks of organization systems that allow organizations to share information and interact electronically across organizational boundaries (Kaufman 1966). These systems enable buyers, sellers, and partners to be incorporated in the redesign of their key business processes and thereby they enhance their productivity, quality, speed and flexibility (Applegate *et al* 1999). Increased information flow in the construction material supply chain can alter the market. Relationships between buyers and sellers may change and it may create new channels of distribution. Internet provides a nearly ubiquitous platform for information sharing between different organizational systems. Accessing Internet is very inexpensive and it provides well-established protocols for security and reliability. Mohanty and Deshmukh (2000) stated that market environment encouraged firms to work in close coordination to optimize the flow in entire supply chain. The management of bi-directional flows of information and knowledge is now being recognized as the most important aspect of managing the supply chain (Lummus and Vokurka 1999). By enabling information sharing between different E-commerce systems for construction material trading, buyers and sellers may operate with lower levels of ambiguity and uncertainty due to the provision of greater volumes of timely and accurate information, thereby enabling them to make more efficient and effective decisions. Emerging technology like data mining and intelligent agents can even automate the exchange of information by unattended computer systems that are programmed to capture and evaluate information and share it with strategic partners.

2.8 Information Standardization

One obstacle to information sharing is the lack of standard data representation schemas. Before the E-commerce systems for construction material trading can communicate effectively, there must be a standard for representing information such as material details, supplier details, trading details, etc., so that the systems can interpret and understand the information. The emergence of eXtensible Markup Language (XML) makes information standardization and communication between different information systems possible and effective. XML is a portable, widely supported, open technology for describing data. XML is becoming the standard for storing data that is exchanged between applications. Using XML, document author can describe any type of data, including material information, project documents, CAD drawings, trading information, etc. XML documents are readable by both humans and machines. XML documents can reference optional documents that specify how the XML documents should be structured. These optional documents are called Document Type Definitions (DTDs) and Schemas. When a DTD or Schema document is provided, validating parsers can read the DTD or Schema and check the XML document's structure against it. If the XML document conforms to the DTD or Schema, then the XML document is valid. DTDs provide a means for type checking XML documents and thus confirming that elements contain the proper attributes and arrangement. Two major standards for representing building and construction data in XML format are bcXML (www.econstruct.org) in Europe and aecXML (www.iai-na.org) in North America. These two standards encourage the spread use of standard information structure to enable communication and information sharing between systems that utilize these standards.

2.9 Approaches to Enabling Information Sharing between E-Commerce Systems for Construction Materials Procurement

To provide better value-added services to the buyers and sellers, I developed the concept of E-Union by linking together relevant E-commerce systems so that communication and information sharing between these systems can be facilitated (Li *et al.* 2002). In the E-Union framework, different construction materials trading sites are joined together by application provided in their information system for intercommunication and information exchange. As illustrated in Figure 2.10, a buyer using one of the E-commerce websites can not only get material information of this site but also material information stored in other sites. All E-Commerce systems under the framework are linked together by an E-Union server. The E-Union server acts as a data center that collects information from its members and passes information to the required members.

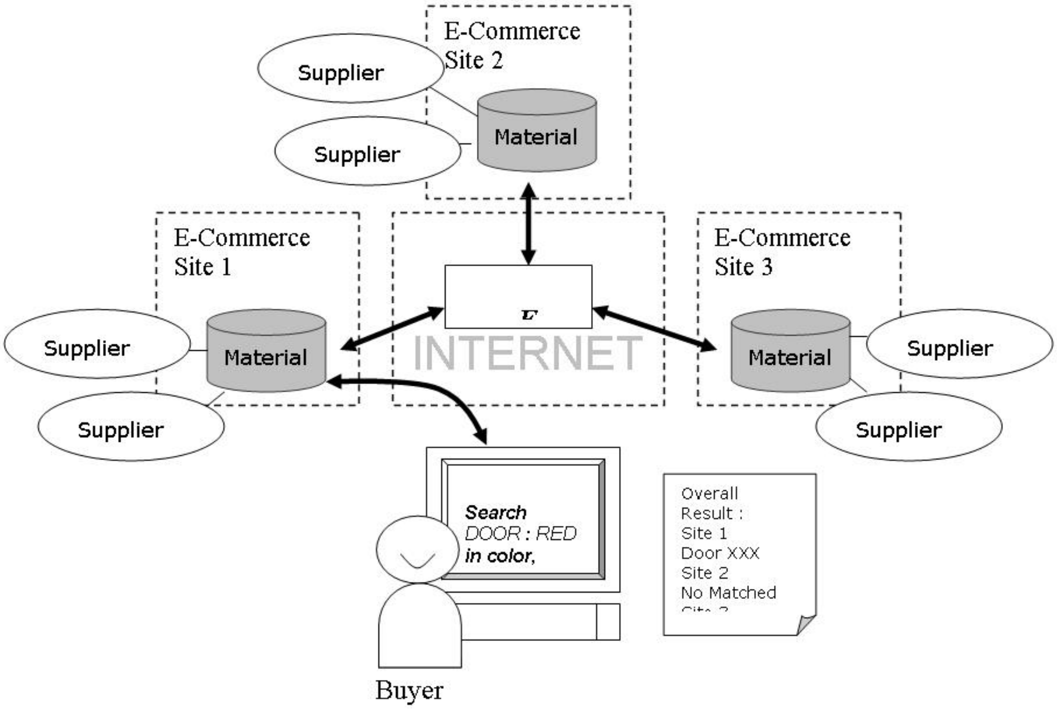


Figure 2.10: Open E-Union framework

Existing E-commerce systems are developed based on different computational architectures, platforms, and software. It is not a trivial task to make them interoperable. There are several issues that need to be addressed for realizing the E-Union concept. The first issue is how an individual E-commerce system finds the service from other sites and communicates with each other. The second issue is how one system understands the various kinds of data from other systems, such as the query, order, and product information. The E-Union framework does not require its members to change their existing data structure, as it is very difficult if not impossible. Instead, the E-Union adopts XML as data representation standard and provides applications to convert its members' data into a standard XML documents for intercommunication. The applications for data collection, conversion, discussion and transmission can be developed by different technologies. The following sections present two approaches for developing these applications: the mobile agent approach and Web services approach.

2.9.1 The Mobile Agent Approach

A mobile agent is a computer program that can autonomously migrate between network sites, i.e., it can execute at a host for a while, halts execution, dispatches itself (together with its data and execution state) to another host, and resumes execution there - all under its own control (Chess 1995, Lange and Oshima 1999). It has been found that mobile agent is especially suitable for structuring and coordinating distributed applications running in a wide-area environment like the Internet (Cao *et al*. 2001, Funfrocken 1999, Gray 2000). Such an environment is characterized by larger number of heterogeneous nodes with dynamically changing services and resources, high variation of connectivity both in performance and in reliability, high variation of workload and network traffic, mobility of hosts, etc. Mobile agents can move through the network of sites to search for, filter and process information they need to accomplish their tasks (Dasgupta 1999, Papastavrou 2000, Sandholm and Huai 2000). Sending mobile agents to the remote server results in a large performance improvement, because they can reduce the number of times one site contacts another and they can filter out non-useful information and thus reduce the consumption of communication bandwidth. Furthermore, a mobile agent brings flexibility and scalability into distributed, dynamic systems due to its ability to encapsulate policies, convention and algorithms and its ability to be dynamically created and destroyed.

In a mobile agent based framework, an E-commerce site joins the E-Union by broadcasting its address and service interface to other members in the union. The membership information is kept at each E-commerce site in a database. Mobile agents are dispatched to other member sites for querying and ordering construction materials that are not available at the local site. The task of a mobile agent consists of traveling along a line of several computer hosts, collecting some input from the hosts and computing result determined by these input. However, a lot of security risks are involved in allowing mobile agents to migrate to other hosts and to be executed. The risks can be categorized into two categories: 1) computer host being attacked by malicious mobile agents, and 2) mobile agents being attacked by malicious host. Successful prevention methods for the first category of risks have been developed, for example proof-carrying codes (Feigenbaum and Lee 1997, Necula 1997), and Lee and Necula 1997), packet filters (McCanne and Jacobson 1993), type safe languages (Bershad *et al*. 1995), and Hsieh *et al*. 1996) and Java archives (Fritzinger and Muller 1996). For the second category of risks, issues to be considered are privacy of computation and the integrity of computation. Both areas are still in their infancies (Biehl *et al.* 1998). Mandry *et al.* (2001) lists out the current prevention methods in this area, which include objects detection, execution traces, fault tolerance, trusted server, time-limit and computing encrypted functions. None of these methods can totally address the risks, and thus there is always a possible attack to a mobile agent by a host.

A mobile agent basically consists of three components, i.e. execution state, program code and data. In the E-Union environment, a mobile agent will probably contain data about construction material information, such as specifications and price, of different E-trading sites. It is possible that a malicious host changes the mobile agent's data, or injects false information to it. As a result, the buyer may get wrong material information and cannot make correct decision on selecting which material to buy.

2.9.2 The Web Services Approach

Web services are used to promote software reusability over distributed systems. Distributed-systems technologies allow applications to execute across multiple computers on a network. A Web service is a class that enables distributed computing by allowing one machine to call methods on other machines via common data formats and protocols, such as XML and Hypertext Transfer Protocol (HTTP). One of the platforms for deploying Web services is the ASP.Net platform developed by Microsoft. In ASP.NET, the method calls are implemented through the Simple Object Access Protocol (SOAP). SOAP is a platform-independent protocol that uses XML to make remote procedure calls over HTTP. Each call and response is packaged in a SOAP message – an XML message containing all the information necessary to process its contents. HTTP was chosen to transmit SOAP messages because HTTP is a standard protocol for sending information across Internet. The use of XML and HTTP enables different operating systems to send and receive SOAP messages. Another benefit of HTTP is that it can be used with networks that contain firewalls, the security barriers that restrict communication among networks. Another reason that Web services use SOAP is its extensive set of supported data types. SOAP can even send and receive attachments. Attachments are the most efficient way to send data such as pictures, XML documents, CAD files, etc. This ability of SOAP is extremely important for interoperation between construction material e-trading sites because material information is often presented in pictures and CAD files formats.

Web services have important implications for B2B transactions. Businesses are now able to conduct their transactions via Web services, rather than via custom-created applications. Because Web services and SOAP are platform independent, companies can collaborate and use each other's Web services without worrying about the compatibility of technologies or programming languages. In this way, Web services are an inexpensive, readily available solution to facilitate B2B transactions. Construction material e-trading sites can easily achieve interoperation by building up their own Web services for other sites to use. A simple example is building material searching and buying Web services that allow approved partner to search and buy their materials. Figure 2.10 illustrates the implementation of E-Union concept by utilizing Web services. In this implementation the E-Union server serves its member by providing members' Web services information and directs the call for Web services to the appropriate member sites. Member sites provide Web services for searching and buying materials in their own site and charge those members who use their services. The material searching criteria and material information input by the E-Union member sites are packed in XML format in SOAP message and are sent across Internet through HTTP. Message integrity and confidentiality can be ensured by the already mature security technologies such as cryptography and hashing.

2.10 Summary

This chapter introduced E-commerce application in construction materials procurement. The traditional construction material procurement process and its limitations were firstly discussed, following by the introduction of E-commerce evolution and its application. Benefits of utilizing E-commerce systems and some security issues are then presented. The later part introduced IEPC and GIS, which are important elements in E-commerce systems. Finally the last section introduced the concept of information sharing in different E-commerce systems and discussed the mobile agent approach and Web services approach for enabling information sharing to maximizing benefits offered by E-commerce systems to there users.

Chapter 3 On-site Material Management Using Automatic Identification Technologies

3.1 Introduction

Automatic identification (Auto-ID) is a broad range of technologies which are used to capture and store electronically readable information, and all are designed to overcome the time consuming and error prone process of data entry using conventional keyboards (Marsh, Flanagan and Finch 1997). Because Auto-ID technologies are used to help machines identify objects, it is often coupled with automatic data capture, and the aim of most Auto-ID systems is to increase efficiency, reduce data entry errors, and free up staff to perform more value-added functions. There are a host of technologies that fall under the Auto-ID umbrella. These include bar codes, smart cards, magnetic stripe, speech recognition, some biometric technologies (retinal scans), optical character recognition, and radio-frequency identification (RFID), etc. (Swartz 1999). Because the Bar codes have been the primary means of identifying products in the construction industry for the past 15 years (see Table 3.1), whilst the RFID is newly introduced to the construction industry but has a potentially wide adoption in the future, this chapter will focus on the bar-coding applications and the main conception of RFID.

3.2 Barcode System

Bar Coding is an Auto-ID technology that streamlines identification and data collection, and the technology of barcode has been applied to many fields since the early 1960s, such as assembly checking, fixed asset inventory control, job costing and tracking, labor distribution, library automation, records management, remittance processing, stock taking, time and attendance, warehouse picking, warranty and service tracking, work-in-process inventory tracking, check-in and billing, receiving, and shipping etc. (SunMax 2001). In the construction industry, barcode technology has been introduced since the late 1980s when the Construction Industry Institute (CII) funded a research project to explore the potential applications and the resulting cost-saving benefits of barcode use in construction (Bell and McCullouch 1988). From then on, barcode technology has been applied in many areas in the construction industry. These areas include quantity takeoff, field material control, warehouse inventory and maintenance, equipment/tool and consumable material issue, timekeeping and cost engineering, purchasing and accounting, scheduling, document control, office operations, and other information management in construction processes of projects (Bell and McCullouch 1988, Bernold 1990, Anderson 1993, McCullouch and Lueprasert 1994, Stukhart 1995, *etc*.). Some research works and applications of barcode technology in the construction industry are listed in Table 3.1.

Table 3.1: Research and Applications of Barcode Technology in Construction

Researchers	Year	Research and Applications
L. C. Bell & B. G. McCullouch	1988	Summarization of the findings of potential applications and the resulting cost-saving benefits of barcode in construction, including field material control, equipment and tool control, document control, office operations, etc.
G. Stukhart *et al*.	1988 ~92	A series of studies on barcode standardization in construction, and two summary thesiss submitted to the CII about barcode standardization in construction, including potential barcode applications, need for barcode standards, approaches to barcode standardization, methodology for developing industry standards, applications of barcode system and barcode standards.
E. J. Lundberg & Y. J. Beliveau	1989	A barcode application system for automated lay-down yard control to reduce loss, theft, misplacement, and misidentification of material and equipment in construction projects.
W. J. Rasdorf & M. J. Herbert	1989 ~90	A barcode application system for a construction information management system, including jobsite resource and activity identification, transfer of data acquisition, work force involvement, and inventory improvement.
L. H. Blakey	1990	A thesis on the results of an application of barcode in a construction-related field, that of facility maintenance, repair, and minor construction.
L. E. Bernold	1990	A research on testing barcode technology in construction environment, including field-testing of barcode labels and adhesives, laboratory testing of barcode labels and adhesives, and the design and development of a pilot yard control system that utilizes the bar-coding concept.
T. L. Brandon & R. A. Stadler	1991	A barcode application system to aid in geotechnical data collection and reduction for conventional sieve analyses.
M. J. Skibniewski *et al.*	1992	Application of barcode technology in robotic materials handling system for automated building construction systems.
A. N. Baldwin *et al.*	1994	An overview of bar-coding techniques and describes in detail the results from a feasibility study undertaken for a major UK supplier of prestressed, precast flooring beams. The research confirmed the technical, economic and operational feasibility of introducing bar coding for materials management within the construction industry.
B. G. McCullouch & K. Lueprasert	1994	Application of 2-dimensional (2D) barcode in construction, including hardware, software, symbology, and using.
Stanley-Miller Construction Co.	1996	Application of ToolWatch® system in central tool warehouse to track everything from small hand tools to large equipment.
D. Echeverry *et al*.	1996 ~98	Implement barcode control in construction projects in Colombia, including a discussion about adaptation of barcode for construction project control, and barcode control of construction field personnel and construction materials.
M. R. Kemme	1998	A barcode tracking system for hazardous waste, including tracking information on hazardous material consumption and generation.
D. Wirt *et al*.	1999	A barcode application system of a wastewater treatment plant project, where barcodes are used to track equipment from receipt to installation, and then is used to interface with an electronic operation and maintenance manual.
W. K. Leung *et al*.	2001	A barcode system for drawing management.
H. Li *et al*.	2002	A barcode system for material control on site based on an Incentive Reward Program (IRP) in order to reduce the generation of construction waste.

3.2.1 Features

The primary function of the bar-coding system adopted in construction material, equipment and document management is to provide instant and up-to-date information of quantities of material, machinery and document exchanged among the managers, the storage keepers and the crew foremen. Specifically, the bar-coding system can provide the following functions to implement IRP for reducing construction waste:

- To automatically capture real-time data of new materials etc. on the site;
- To automatically capture real-time data of unused materials etc. on the site;
- To automatically capture real-time data of packing of materials and equipments;
- To automatically capture real-time waste debris of materials etc. on the site;
- To automatically record historical data of materials etc. consumed in the project;
- To automatically monitor materials consumption of crews;
- To automatically transfer real-time data to project management system;
- To automatically transfer real-time data to head office via Intranet and/or Internet.

The architecture of the bar-coding system used in material and equipment management on site is illustrated in Figure 3.1.

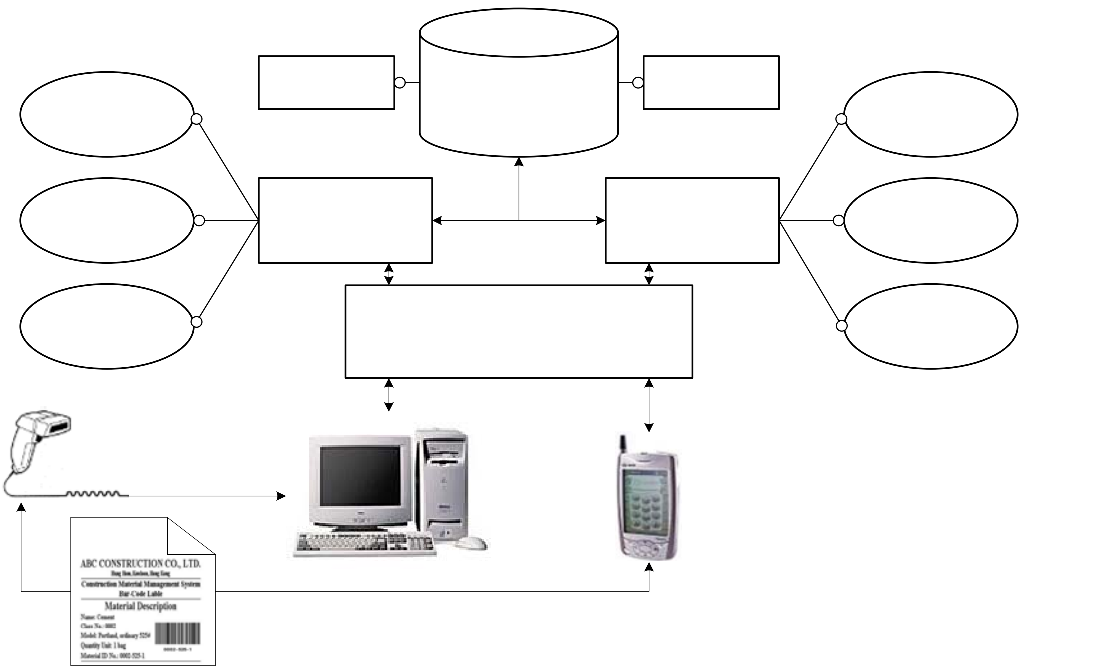


Figure 3.1: Bar-coding system for material & equipment management on site

The Figure 3.1 illustrates a bar-coding system for material and equipment management on site. There are three functions for each of the material management sub-system and the equipment management sub-system, including data capture and save into the database of materials and equipments, data acquire for managers, store keepers and crews, and data reuse for decision-making based on material and equipment information such as construction planning and construction budgeting. The system provides two types of data capture including the mobile and the immobile data capture (see Figure 3.1).

3.2.2 Hardware System

The hardware system of the bar-coding application consists of the barcode scanner and the computer. A basic barcode scanner consists of a scanner, a decoder, and a cable that interfaces between the decoder to the computer or terminal. Although there are four basic styles of barcode scanner: light pen (usually called wand), linear CCD (Charged Couple Device), laser and video (CCD array), the most versatile barcode scanners are laser scanners, and many scanners have the decoder logic incorporated into a chip within the scanner, eliminating the need for a separate piece of hardware (PIPS, 2001). The scanner I selected is PSC QuickScan 5385 scanner with keyboard wedge type of decoder integrated, which allows barcode scanning to be added to almost any application without modification to the application software (PIPS, 2001). Figure 3.2 describes schematic components of the immobile bar-coding hardware system.

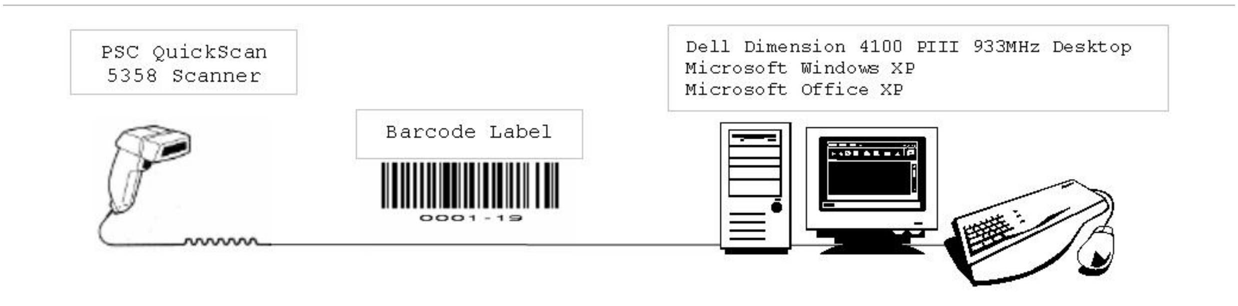


Figure 3.2: Components of bar-coding hardware system

3.2.3 Software System

The software system for a barcode technology includes two essential software: barcode-labeling software and barcode-tracking software. Barcode technology providers such as Loftware LLM-WIN32, BAR-ONE, and BarTender, provide fast and easy to use barcode-labeling software for designing and printing quality labels. Barcode-tracking software, such as IntelliTrack and Inventory Manager, can be used to read and track the barcodes. The barcode adopted here is the Code 128 symbology (Stukhart 1995). Software named "LLW-Win32 Design" (Version 7.x) from Loftware label printing systems is used to design the identification labels, and all bar-coding labels are printed out through a HP LaserJet printer.

Because bar-coding labels can be easily damaged during transportation and items of construction materials are cumbersome for the storage keeper to scan the barcode labels if they are adhered onto the items/packs, I prepared a handbook of bar-coding labels for all kinds of the construction materials used on different sites. This handbook contains all the barcodes and is maintained and used by the material storage keeper.

3.2.4 Material Identification

For the materials, the bar-coding labels are designed to represent a material and its model, *etc*. For examples, the code *0002-525-1-XYZ* represents “Cement – Portland, Ordinary 525# - 1 standard bag - XYZ Trademark”, the code *0201-003-1-Local* represents “Aggregates – 3 mm particle diameter - 1 cubic meter – Local provenance”, as shown in Figure 3.2. The "Class No." in Figure 3.3 is used to represent names of different materials, and the total number of the "Class No." is set as 2,000.

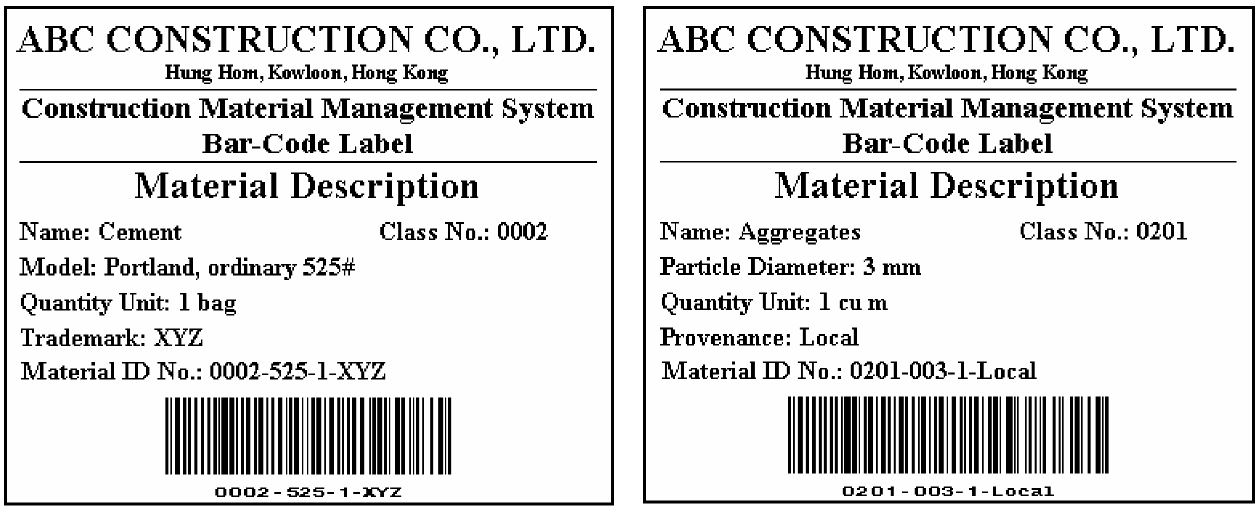


Figure 3.3: Sample bar-coding labels for construction materials

3.2.5 Crew Identification

For each crew or working group, an identification label is issued to the group foreman, who is responsible for withdrawing and returning construction materials. Figure 3.4 gives a sample identification label for a working group.

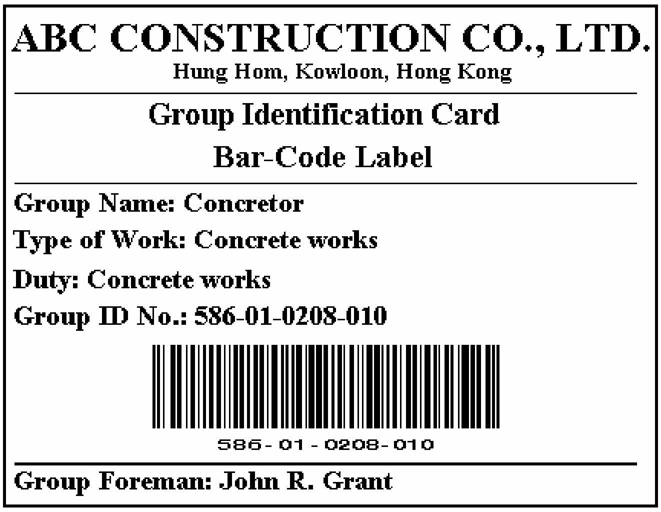


Figure 3.4: Bar-coding label for a Carpenter group

The barcode of the crew represents the group and its leader. For example, coding number *586-01-0208-010* represents "Concretor group 586 and its foreman's staff ID number is 01-0208-010", as shown in Figure 3.4. By scanning the barcodes for the materials and the crew, the computer system keeps records of materials used or returned by the crew. These records are then used to calculate the reduction and increase of material wastes generated by the crew.

3.3 Radio Frequency Identification

Radio Frequency Identification (RFID) is a generic term for technologies that uses radio waves to automatically identify individual items, such as packaged building materials in construction. There are several methods of identifying objects using RFID, but the most common is to store a serial number that identifies information of material or equipment, etc. on a microchip that is attached to an antenna (the chip and the antenna together are called an RFID transponder or an RFID tag). The antenna enables the chip to transmit the identification information to a reader. The reader converts the radio waves returned from the RFID tag into a form that can then be passed on to computers that can make use of it.

Bar codes have been the primary means of identifying products for the past 25 years. During that span, they have served their purpose well. But bar codes have one big shortcoming: they are line-of-sight technology. That is, a scanner has to "see" the bar code to read it, which means people usually have to orient the bar code towards a scanner for it to be read. RFID, by contrast, doesn't require line of sight. RFID tags can be read as long as they are within range of a reader.

Bar codes have other shortcomings as well. If a label is ripped, soiled or falls off, there is no way to scan the item. And standard bar codes identify only the manufacturer and product, not the unique item. The bar code on one milk carton is the same as every other, making it impossible to identify which one might pass its expiration date first.

RFID is a proven technology that's been around since the Second World War. Up to now, it's been too expensive and too limited to be practical for many commercial applications. But if tags can be made cheaply enough, they can solve many of the problems associated with bar codes. Due to this reason, the adoption of the RFID in the construction industry will only be realized in the future, but the research and development interest on the RFID application system in the construction industry still exist.

3.4 Experimental Results

In order to examine the effect of the group-based IRP, we conducted two experiments by using two couples of residential blocks in two public housing projects in Hong Kong. Each project involved constructing two identical 34-storey residential blocks using a 6-day construction cycle. The 6-day cycle included nine major activities undertaken by nine working groups. The two blocks were constructed simultaneously by two teams of workers, each team having nine working groups with equal numbers of workers to carry out the 6-day cycle construction method. We labeled the two teams as Team A and Team B. For the purpose of comparison, Team A did not adopt the group-based IRP during their operations, while Team B implemented the IRP with our advice and support.

Table 3.2. Experimental Result without Group-based IRP (Team A)

Materials	Unit	Group		$Q^i_{estimated}(j)$	$Q^i_{delivered}(j)$	$Q^i_{returned}(j)$	$\Delta Q^i(j)$	P_i	$C(j)$
		Name	Duty						
Rebar	ton	Steel bender	Fix wall rebar	1760.00	1798.72	0.00	-38.72	2271.31	-87945.12
			Fix slab rebar	1408.00	1430.88	0.00	-22.88	2271.31	-51967.57
Precast facade	set	Rigger	Place precast façade	1760.00	1760.00	0.00	0.00	3000.00	0.00
Precast slab	set		Place precast slab	9856.00	9856.00	0.00	0.00	1500.00	0.00
Cement	ton	Concretor	Concrete wall	31680.00	31715.20	0.00	-35.20	640.80	-22556.16
			Concrete slab	10560.00	10630.40	0.00	-70.40	640.80	-45112.32
		Plasterer	Fit up wall, ceiling & floor	15400.00	15492.40	0.00	-92.40	640.80	-59209.92
Sand	cubic meter	Concretor	Concrete wall	26928.00	27068.80	0.00	-140.80	57.04	-8031.23
			Concrete slab	10560.00	11158.40	0.00	-598.40	57.04	-34132.74
		Plasterer	Fit up wall, ceiling & floor	24024.00	24578.40	0.00	-554.40	57.04	-31622.98
Cobblestone	cubic meter	Concretor	Concrete wall	26752.00	27420.80	0.00	-668.80	58.30	-38991.04
			Concrete slab	10560.00	10771.20	0.00	-211.20	58.30	-12312.96
Hydrated lime	ton	Plasterer	Fit up wall, ceiling & floor	9394.00	9732.80	0.00	-338.80	464.00	-157203.20
Plywood formwork	square meter	Carpenter	Fix timber slab form	26400.00	26892.80	0.00	-492.80	57.20	-28188.16

Nail	bag		Fix timber slab form	1760.00	2200.00	0.00	-440.00	50.10	-22044.00
Drywall board	square meter	Rigger	Install wall board	9460.00	9702.00	0.00	-242.00	164.00	-39688.00
Block	10k blocks	Bricklayer	Bond masonry wall	2.20	2.31	0.00	-0.11	7296.12	-802.57
Embedded plastic conduit	meter	Electrician	Concel conduit installation	18480.00	20257.60	0.00	-563.20	1.05	-591.36
Glass	square meter	Glazier	Install window glass	8078.40	8474.40	0.00	-396.00	27.80	-11008.80
Paint	square meter	Painter	Fit up minor works	468.60	497.20	0.00	-28.60	25.00	-715.00
Wall tail	square meter	Plasterer	Fit up wall	22704.00	23628.00	0.00	-924.00	34.00	-31416.00
Mosaic	square meter		Fit up wall and floor	10824.00	11325.60	0.00	-501.60	89.60	-44943.36
			Total(HKD)						**-728482.49**

Table 3.3. Experimental Result with Group-based IRP (Team B)

Materials	Unit	Group		$Q^i_{estimated}(j)$	$Q^i_{delivered}(j)$	$Q^i_{returned}(j)$	$\Delta Q^i(j)$	P_i	$C(j)$
		Group name	***Duty***						
Rebar	ton	Steel bender	Fix wall rebar	1760.00	1726.56	8.80	42.24	2271.31	95940.13
			Fix slab rebar	1408.00	1365.76	7.04	49.28	2271.31	111930.16
Precast facade	set	Rigger	Place precast façade	1760.00	1760.00	0.00	0.00	3000.00	0.00
Precast slab	set		Place precast slab	9856.00	9856.00	0.00	0.00	1500.00	0.00
Cement	ton	Concretor	Concrete wall	31680.00	31539.20	14.08	154.88	640.80	99247.10
			Concrete slab	10560.00	10454.40	17.60	123.20	640.80	78946.56
		Plasterer	Fit up wall, ceiling and floor	15400.00	15307.60	18.48	110.88	640.80	71051.90
Sand	cubic meter	Concretor	Concrete wall	26928.00	26681.60	126.72	373.12	57.04	21282.76
			Concrete slab	10560.00	10419.20	225.28	366.08	57.04	20881.20
		Plasterer	Fit up wall, ceiling and floor	24024.00	23839.20	117.04	301.84	57.04	17216.95
Cobblestone	cubic meter	Concretor	Concrete wall	26752.00	26611.20	140.80	281.60	58.30	16417.28
			Concrete slab	10560.00	10489.60	105.60	176.00	58.30	10260.80
Hydrated lime	ton	Plasterer	Fit up wall, ceiling and floor	9394.00	9363.20	0.00	30.80	464.00	14291.20
Plywood formwork	square meter	Carpenter	Fix timber slab form	26400.00	26241.60	140.80	299.20	57.20	17114.24
Nail	bag		Fix timber slab form	1760.00	1672.00	79.20	167.20	50.10	8376.72
Drywall board	square meter	Rigger	Install wall board	9460.00	9394.00	0.00	66.00	164.00	10824.00
Block	10k blocks	Bricklayer	Bond masonry wall	2.20	2.15	0.22	0.28	7296.12	2006.43
Embedded plastic conduit	meter	Electrician	Concel conduit installation	18480.00	18286.40	158.40	352.00	1.05	369.60
Glass	square meter	Glazier	Install window glass	8078.40	7946.40	52.80	184.80	27.80	5137.44
Paint	square meter	Painter	Fit up minor works	468.60	464.20	2.20	6.60	25.00	165.00
Wall tail	square meter	Plasterer	Fit up wall	22704.00	22572.00	105.60	237.60	34.00	8078.40
Mosaic	square meter		Fit up wall and floor	10824.00	10744.80	118.80	198.00	89.60	17740.80
			Total(HKD)						**627278.69**

Each experiment has been conducted over three months. Results of the second experiment from Team A and B during the three months are listed in Table 3.2 and 3.3. The first column of the tables is the list of major materials used in the 6-day cycle. The second column is the unit of the materials; the third column contains the group names and their tasks. Columns 4~6 list estimated quantities of materials, quantities of materials delivered to groups, and quantities returned by groups. Column 8 lists the prices of materials, while Column 7 and 9 list results of calculations based on sets 1 and 2. From the experimental results, it can be observed that throughout the three months, Team A consistently wasted more construction materials than Team B, because workers in Team A did not see the benefits of reducing wastes. Therefore, by the end of three months, Team A has wasted additional amounts of construction materials valued at 93,395.19 USD (728,482.49 HKD). On contrast, Team B has made a substantial saving of 80,420.35 USD (627,278.69 HKD), indicating that the group-based IRP had effectively motivated workers in Team B in reducing avoidable wastes, and the difference between the two projects is 173,815.54 USD (1,355,761.18 HKD). Because the cost of the bar-coding system is about 26,536.60 HKD (see Table 3.4), Team B saves 600,742.09 HKD. These results convinced us that the group-based IRP is effective in reducing construction wastes. Moreover, the experiment reinforces that the bar-coding system can achieve cost savings for contractors. Comparing to the total cost of the bar-coding system that is given out in Table 3.4, the savings obtained from the reduction of material waste are much higher than the initial investment of the bar-coding system with an approximate proportion of 22.87:1 (Case 2 in Table 7), while it is 22.58:1 in the first experiment (Case 1 in Table 3.4), and the result from the first experiment is quite similar to the second one's.

Table 3.4. Cost analysis of the bar-coding system and its profit

		Item	**Value (USD)**	**Value (HKD)**
Invest	System	PSC Quickscan 5358 Scanner	819.00	6,388.20
		Dell Dimension 4100 PIII 933MHz Desktop	870.00	6,788.00
		Loftware LLM-WIN32 Design (Version 5.x)	795.00	6,200.00
		MS Windows 2000	319.00	2,488.20
		MS Office 2000	599.00	4,672.20
		Total invest cost of the bar-coding system	3,402.00	26,536.60
Profit	Experiment 1			
	Team A	Total value of additional waste materials	95,890.73	747,947.71
	Team B	Total value of saved materials	90,428.83	705,344.85
		Repay rate of the investment (%)		2558.00
	Experiment 2			
	Team A	Total value of additional waste materials	93395.19	728482.49
	Team B	Total value of saved materials	80420.35	627278.69
		Repay rate of the investment (%)*		2287.70

Annotation: * The repay rate of the investment is calculated with a depreciation rate of 1%.

Comparison between the two experimental results shows that both of the total amount of additional waste materials and saved materials in experiment 2 are smaller than what is in experiment 1. In fact, after the first experiment, we reduced the quantity of materials in construction budget moderately according to the first experimental result. So Team B can only reach a lower saving level under high quality supervisions in the second experiment, while Team A can still ask for additional materials within the budget.

3.5 Summary

This chapter introduces the technique of Auto-ID and two types of its applications to the construction industry, including barcode technique and RFID technique. Although the RFID technique is advanced than the barcode technique, it is suspended in this thesis due to the feasibility of the RFID system adopted in the construction project management at present, however, the advantage of the RFID technique indicates its potential adoption in construction project management. As a result, the author of this thesis recommend that the barcode technique and its application system, such as material and equipment management system be adopted in construction project management.

Chapter 4 Web-based Construction Project Information System

4.1 Introduction

The construction industry is an information rich industry, both in terms of the information it generates and exchange among participants, as well as the information it absorbs from outside sources. The effective management and transfer of information are crucially important to the successful completion of construction projects. Construction projects necessarily involve more organizations coming from different geographical locations. The task of coordination and information sharing/exchange therefore becomes very challenging. Although some IT tools such as email, video-conferencing, electronic networking, multimedia technologies, have been used to enhance communication and data/information transfer, these tools are used in a discrete and uncoordinated manner. Integration of these tools can certainly improve the efficiency and effectiveness. On the other hand, the fragmental, dynamic and one-off nature of the construction project management processes implies that without an integrated information system, project-specific information cannot be stored appropriately for generating knowledge and future use. Moreover, it has been discovered that up to 50% of project managers' time is spent on searching for required information. This contributes significantly to the efficiency loss during the project management (Wong et al. 2000).

In order to solve these problems, internet technology has been applied recently to speed up and simplify communications, to share information among different participants of construction projects. Particularly, web-based project management systems (also called project hosting systems) have been developed to achieve seamless information flows in project management practice. As an example of such systems, VHBuild™ , an on-line project management information system developed by VHSoft Technologies Co. Ltd., has been put in uses in Hong Kong and mainland China's housing projects. This chapter uses VHBuild™ as an example to introduce the application of state-of-the-art information technology in construction project management. A questionnaire survey was conducted to reveal benefits as well as the challenges in using a Web-based project management system. Details of the questionnaire is given in Appendix 1.

4.2 Current Practice and Problems Identified

In any construction project, there exists numerous parties involved in its execution such as the developer, architect, engineer, main contractor, nominated subcontractor, direct subcontractor and supplier. A project inevitably generates a huge volume of documentation such as letters, drawings, photographs, site instructions and so on. Documents are generated on a daily basis: drawings are revised, plans and designs are amended and so on. In order for the project to proceed smoothly, it is vital that all relevant documentation and information reaches the relevant parties.

The nature of a construction project is highly dynamic and changes take place constantly throughout the course of the project. Any changes or revisions, whether major or minor, have to be recorded and approved by all relevant parties, as they will impact on the contractual obligations between one or more of the parties. It is thus vital to ensure that all revisions and instructions are promptly sent to the different parties for their action. Very often the same document or instruction has to be sent to numerous companies participating within the contract, as well as to multiple individuals within each company.

Prior to the advent of the Internet, communications between multiple parties relied on physical copies of the relevant documents being sent to the appropriate parties. This system for the dissemination and distribution of information is fraught with problems such as filing of large volume of documents, ensuring rapid access to up to date information, ensuring all relevant documents reach the appropriate parties and the sheer logistics behind the delivery of such a large amount of information to varying locations. Further disadvantages of the manual system for distribution of documents is that documents can often be misfiled, mislaid or simply lost in transit.

It is not unusual for different parties on a project to be located in different countries and so the issue of distribution and circulation of documents becomes further exacerbated. Often the usual means of distribution such as faxes and couriers are not good enough or too slow. Thus for example if the company preparing the drawings is based overseas it can become difficult for drawings to be sent back and forth to effect revisions and changes. Often the only practical way to send such drawings is by courier. This not only gives rise to escalating costs but can also add to delays in finalizing the drawings.

4.3 Business Model of Construction Project Hosting System

Due to the inherent nature of construction projects and the contractual relationships contained within, any project hosting system requires a system model which not only allows multiple parties to efficiently access to project data but also maintains a highly secure and confidential platform for all participants to seamlessly integrate within so as to enhance their current business and workflow practices

Currently two standard business models have been adopted for developing project hosting systems: corporate intranet based model (Figure 4.1) and common platform Internet based system (Figure 4.2). Although both system models have their unique advantages, they all contain fundamental flaws making them ultimately unsuitable for online construction project management. For the corporate Intranet model, the disadvantages include its insecurity in protecting the system from accesses of unauthorized users; its rigidity on having a single administrator to manage all the data and information on the system for all the internal and external parties/users; and its inability to provide a secure and private environment for external users to store their project data (Wong et al. 2002).

The Internet model, on the other hand, has also some disadvantages. These disadvantages include, first, it frequently involves a ‘super’ administrator who can oversee all the project data and files, making other users feel insecure for storing their data on the system. Moreover, as the Internet model only support a particular workflow embedded in the system. This creates problems for participating organizations as they may adopt different workflows in their practices. In addition, the Internet model does not have a clear definition and clarification on the ownership of project data stored in the system. The following sections further discussed the problems with the corporate Intranet model and Internet based model.

4.3.1 Intranet-based Project Hosting Model

An Intranet is a computer network established within an organization in order to facilitate better communications among its employees. As an Intranet is designed for internal use, users from outside of the organization (owner of the Intranet) have to be granted with authority before they can get access to the Intranet system.

In an Intranet based project hosting system, the organization who owns the Intranet obviously has the overall authority in granting access rights to other organizations involved in a construction project. The owner organization can also oversee all the project data and information. These ‘privileges’ effectively enable the owner organization to be a ‘super’ administrator of the Intranet based project hosting system.

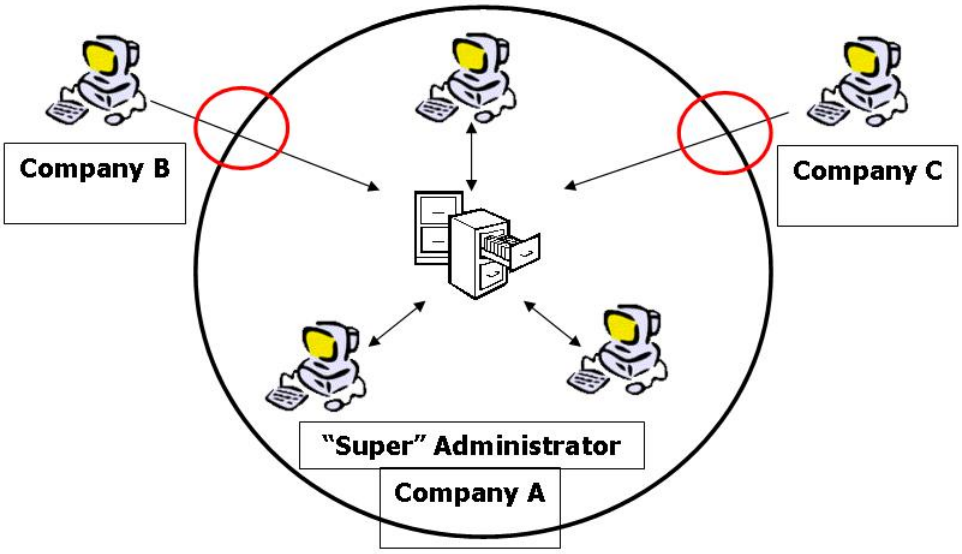


Figure 4.1: Schematic intranet project hosting model

The problems of the Intranet based project hosting system are further explained as follows:

- **Security confined within a company** – Individuals and departments communicate and share information within the confines of a secured internal network owned by one organization.
- **Insecure external third party access** – External organizations working on the same projects must be granted certain access rights beyond the secure network barrier so as to access and transmit data. This poses an unacceptable security risk to the project hosting system as well as the owner organization.
- **Single administrator for all companies** – All access to the information will ultimately be under the administration of a single party, invariably the IT department of the owner organization. It could be prove difficult for all parties to accept the administration of another company over their staff and users.
- **Disincentive for external party to post/store data** – Confidentiality cannot be assured to the external organizations which post information within an Intranet

based project hosting system owned by another organization. This acts as a disincentive for other organizations to use such a system.

Because of the above reasons, the Intranet based project hosting system is perceived as unsuitable for use in construction projects where involvement of multiple organizations is inevitable.

4.3.2 Internet Based Project Hosting Model

An Internet based project hosting system, on the other hand, uses the Internet as the communication backbone to facilitate the share and exchange of project information among participants (Figure 4.2). The 'conventional' Internet based project hosting model, however, still requires an organization to own/host the project hosting system and project information is still stored within the owner organization. Compared to the Intranet based project hosting system, the Internet based project hosting system does not has the risk of jeopardizing the internal security of the owner network when allowing external parties to use the project hosting system, as the Internet is designed for external users and mature technologies are available to prevent unauthorized users from hacking into the internal networks.

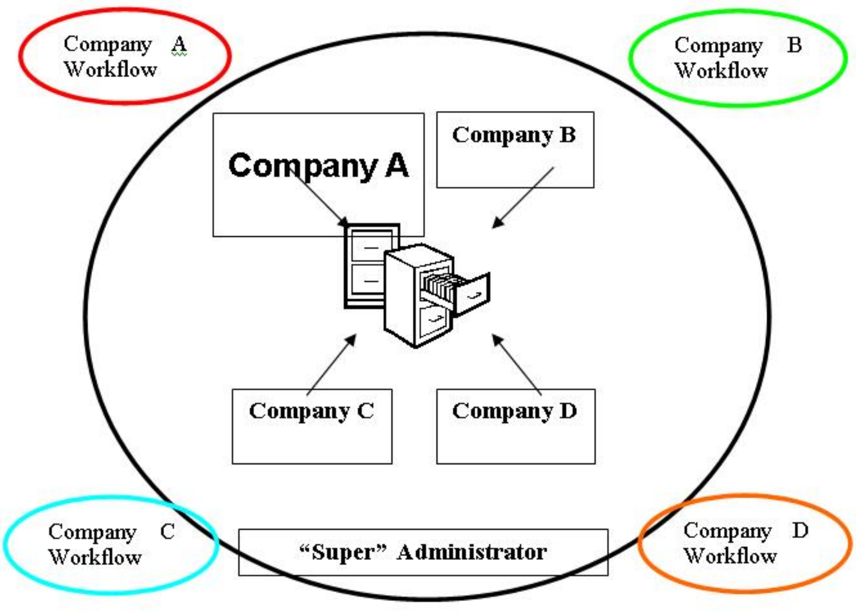


Figure 4.2: Schematic 'conventional' Internet project hosting model

Nevertheless, the conventional Internet based project hosting systems still suffer the following disadvantages:

- **Single "super" administrator for multiple companies -** The project platform is once again ultimately administered by a single "super" administrator, ie, the owner organization of the project hosting system. The 'super' administrator will initiate user accounts and be potentially able to have access to cross project information.
- **Rigidly defined workflow creates incompatibility with internal practices of individual organizations -** No two companies are the same and each has its own unique document management and workflow. By utilizing a centralized set of project based data, only one management system can exist, thus creating incompatibility for most companies as their existing workflow cannot be incorporated into the project hosting system.
- **Confused data ownership and management -** Although project information and data are created by various parties in the Internet based project hosting system, these project information are data are stored and managed in the central database. Without a clear definition of the ownership, it becomes very confusing to project participants on who has the responsibility for what information.
- **Lack of confidentiality for communications -** The "super" administrator is potentially able to monitor and tap into all communications performed via the platform. For example, company B and C may wish to communicate confidentially, however company A as the administrator may be able to access that information without the consenting of B and C.

Due to the above disadvantages of the conventional Internet based project hosting model, this model does not suit the existing industry practices and thus the model cannot be directly adopted in developing project hosting systems for assisting construction project management.

4.2.3 VHBuild^{tm} Project Hosting Model

The VHBuild™ system, however, has developed a unique project hosting model which overcomes the disadvantages existed in the previous Intranet and Internet based project hosting model. The key features of the VHBuild™ system can be summarized as follows, 1) the token authenticators provide users with the maximum security in protecting their project information stored in the system; 2) the data center, which is owned by an impartial third party, stored project data and information that is controlled and managed by individual organizations involved in a construction project; 3) users can define their own workflow and data processing procedures within the VHBuild™ system to suit their own practices; 4) ASP model enables users to have access to the updated functions without the need of paying additional fees for upgrading and maintaining the system.

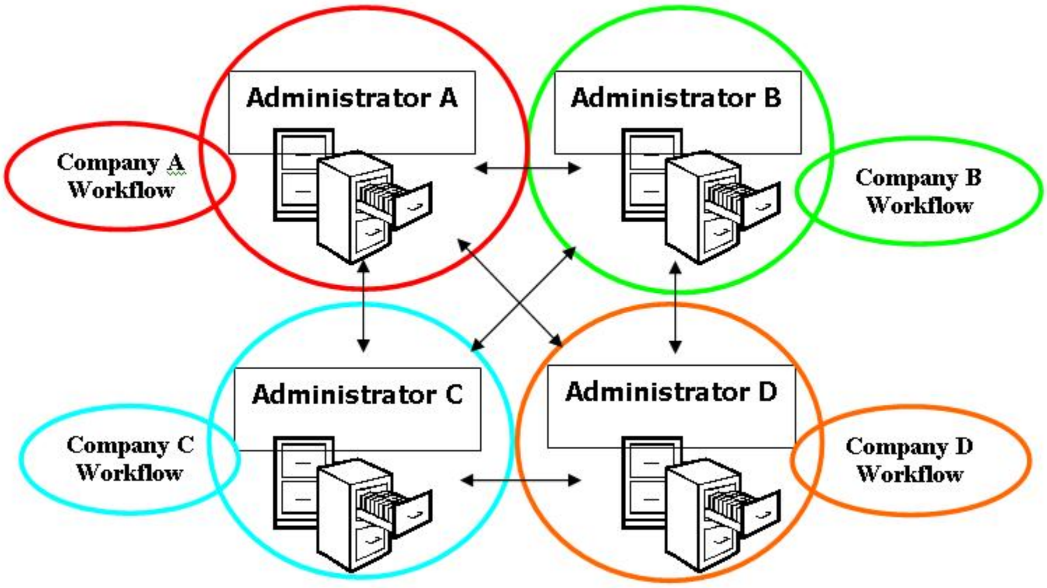


Figure 4.3: VHBuild™ project hosting model

The key features are further elaborated below:

- **Self administered accounts with no "super" administrator -** Each company maintains their individual corporate and project accounts that can be selectively linked with other company accounts working on the same project. Each project account is self-administered.
- **Allows existing company workflow to be integrated -** Because each company maintains their own "de-centralised" database, existing document management practice can be easily integrated as the information is company based not project based.
- **Completely internal data ownership and management -** Each project participant possesses its own copies of the relevant project files and information as they wish. By matching the existing practice, this eliminates confusion over data management and ownership.
- **Accommodates discreet confidential communications -** Self-administered company accounts allow project teams from different companies to perform discreet and confidential communications with no central super administrator having access to the communications.

- **Matches current construction practice -** For the above mentioned reasons, the VHBuild™ working model meets the functional requirements of the end users without compromising security or privacy. By allowing reflexibility for users to define their own workflow and information processing procedure, the VHBuild™ system provides a convenient tool for companies to integrate their current practices in the VHBuild™ environment.
- **Enable inter and intra –company communication in a secured environment –** The business model of VHBuild™ is built in such a way to enable company to company communication and department to department communication in a private, confidential and secured environment. This can never been done in the 2 different models that I described above. This business model will also enable different parties in the project to freely contribute information to VHBuild™ with trust. This model exactly simulates the current construction practice and business process.

In summary, VHBuild™ provides a model that delivers information securely and confidentially. By empowering the end users with complete internal autonomy whilst allowing participants to smoothly communicate, construction best practice and relationships are adhered to.

4.3 Functions of Project Hosting System that Address Business Needs

This section uses VHBuild™ system as an example to illustrate functions of project hosting system that address business needs.

4.3.1 Web Cam / Site Photos

A construction site is often remote from the offices of the client and senior members of the project management team, it is difficult for them to frequently travel to the site to proactively monitor the site status and emerging situations due to time and distance restraints. The provision of real time web-cams at strategic positions around the site allows the client and senior management the ability to monitor the site progress on a macro basis. Site photographs taken and uploaded by site personnel allow the client and senior management to track the site works and issues on a more detailed, micro basis. The information can be transmitted from the site to the client and senior management's computers in their respective offices within a matter of minutes as opposed to days under the conventional practices.

4.3.2 Multiple Recipient Distribution / Circulation

In any construction project, there exist large volumes of paper-based documents which include multiple copies of documents, meeting minutes, drawings, memo's and so on. This is not only environmentally unfriendly but also inefficient way of using resources due the need of making and distributing the multiple copies of the same documents.

Distributing electronic copies as opposed to paper copies dramatically reduces excessive paper wastage along with required storage needs. Furthermore, the electronic files can be distributed to all parties on the project in an easy single operation, thus greatly improving workforce efficiency by eliminating the previous labour intensive exercise.

4.3.3 Drawing Mark Up

In the conventional project management practice, design reviews and changes along with queries cannot readily be accessed by appropriate individuals due a lack of co-ordination on drawing mark-ups and a slow turnaround of the comments brought about by communication and distribution inefficiencies.

A streamlined review and comment process is possible by using the functions in the VHBuild™ system to mark up electronic copies of drawings online and distribute them in a timely manner. A suite of advanced mark up options is available within the system allowing internal reviews to be performed on the same drawing, thus reducing co-ordination amongst team members. Furthermore, multiple mark up layers can be saved so as to avoid confusion caused by comments from different parties. Through the distribution channel of the VHBuild™ system, all parties involved in a particular project can received the drawings with marked comments.

4.3.4 Powerful Search Engines

Information retrieval is a very time consuming and frustrating activity in the conventional project management practices. An estimated over 100,000 documents are produced from a typical construction project, even if all the documents are electronically stored, retrieving a relevant piece of information from the huge amount of documents is still tedious and time-consuming. Search engines within the VHBuild™ system allow all users to retrieve a file or thesis efficiently. Specifically, the search engines allow multiple search fields which enable users to customize their search to a wide and detailed scope. Search results are produced within seconds. This is of particular use during the project duration in which the volume of information increases rapidly, as well as during the post-contract claims settlement period in which information from all project stages must be retrieved.

4.4 Barriers in Adopting Project Information Management System

This section presents results identified from a survey study which has been conducted upon all users of the VHBuild™ system in the Tseung Kwan O Area 73 Phase 2 (121/99) project. This survey collected opinions from the users in the form of questionnaire survey and face-to-face interviews. The users include the Senior Architect, the Project Architect, the Project Structural Engineering, the Clerk of Works, the Site Agent and the Deputy Site Agent. The results reflect the current situation in Hong Kong only.

4.4.1 Culture

The construction industry has some distinct features in the way it conducts its business, which makes it different from other industries such as the manufacturing industry. So far IT has not had the same level of penetration in construction as it has had in the manufacturing industry. This is possibly because of the fragmented nature of the construction industry, and the one-off nature of its production. Figure 4.4 shows the level of IT use in Hong Kong construction industry estimated by the people participated in the questionnaire survey. Thirty-three percents of the respondents agree that the Hong Kong construction industry utilizes IT in construction project management just fairly and 67% of them think that IT is rarely used.

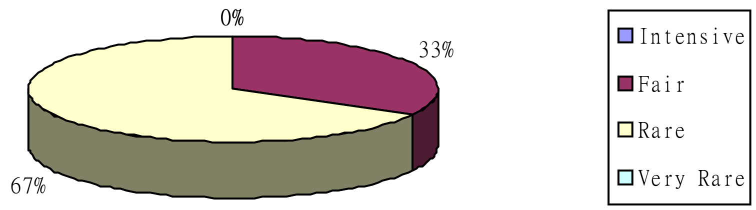


Figure 4.4: Comment on utilization of IT in the Hong Kong construction industry

Implementation of IT requires changes in organization and people. Change in any field of human activity inevitably means changing the status quo from which the majority of people in work derive their economic and emotional security. Change is therefore initially resisted until those people whom it will affect can see it as an opportunity and benefit rather than a threat and disadvantage. The construction industry, and those who work in either the design or the construction firms which it comprises, is no exception to resistance to change and because of its traditional historic roots as an industry, is more resistant than most. However, its people, whether designers or contractors, are by the very definition of their work very practical and therefore often skeptical of new ideas, technological or managerial, unless the advantage is very obvious, preferably in the short term and they can see how it will help them on their next project.

Benefits of IT application in construction project are recognized by professionals of many countries. From Table 4.1 it can be seen that most of the questionnaire survey respondents agree that IT tools can 1) bring all project participants to work together more efficiently and effectively, 2) improve information flow along the construction value chain, and 3) let people retrieve information easily. Automation of repetitive task is also recognized by 33% of the questionnaire survey respondents as a benefit offered by IT.

Table 4.1: Benefits of IT tools in construction project

Benefits	**Rate of agreement**
Bring all project participants to work together more efficiently and effectively.	67%
Improve information flow along the construction value chain.	67%
Automate repetitive task.	33%
Easily retrieve information.	100%

The pay-off for implementing IT must be financial in the first instance and will only come when implementing IT resulting in each business firm represented receiving the expected profit. This in turn will only happen if ‘wasted time’ or, even worse, ‘rework’, which can be ‘redesign’ or ‘reconstruction’ depending on the team member’s function, is minimized and altogether eliminated. The link between implementing IT and reduced wasted time and rework is that the former should provide a platform for good communication and the sharing and exchange of information at the right time during the evolution of the project. This is because wasted time and rework have been often caused by miscommunication and untimely information exchange between project participants, essentially between designers and main contractors or specialist trade contractors.

A clear way forward for the construction industry is to follow the example of the manufacturing industry, and develop a strategy of adopting IT in stages. The UK National Economic Development office argued that the adoption of IT and electronic data interchange will cut UK building costs by 15 to 25%. However, just like any other country, Hong Kong has its own barriers to implementing IT application in construction projects. The barriers include 1) fragmented nature of the project team which make adoption of common IT tools across disciplines difficult, 2) lack of centralized data system and common IT platform, 3) lack of practical application solution in the market that suit Hong Kong construction market, 4) lack of IT application with Chinese interface, 5) low awareness of IT benefits in management level, 6) low level of IT knowledge among construction practitioners, and 7) work flow change not inline with IT tools implementation. Table 4.2 (derived from Q. 1.1.5) shows that barriers (1) to (3) are recognized by most of the questionnaire survey respondents. Some barriers suggested by the questionnaire survey respondents are incompatible electronic file formats such as the drawing files provided by the Housing Authority, and the lack of facilities to utilize IT application.

Table 4.2: Barriers to implement IT in Hong Kong construction project

Barriers	Rate of agreement
Fragmented nature of the project team which make adoption of common IT tools across disciplines difficult	67%
Lack of centralized data system and common IT platform	67%
Lack of practical application solution in the market that suit Hong Kong construction market	67%
Lack of IT application with Chinese interface	33%
Low awareness of IT benefits in management level	33%
Low level of IT knowledge among construction practitioners	50%
Work flow change not inline with IT tools implementation	17%

Some suggested solutions for overcoming the above barriers in implementing IT application are 1) strong local customer services, support and training, 2) customized application and services, 3) supporting staff from the IT provider with adequate local construction knowledge, 4) providing IT applications that do not require too many changes to the existing workflow, 5) providing IT applications that do not require too much learning and training, 6) providing IT applications with Chinese interfaces, and 7) standardization of IT tools, platforms and digital formats. From table 4.3 it can be seen that 100% of the questionnaire survey respondents agree that IT applications that do not require too many changes to the existing workflow and do not require too much learning and training are easier to be implemented. It indicates that they concern very much on the change of their practice.

Another favorable solution is to have strong local customer services, support and training. The reason for this may be due to the influence of some unsuccessful cases of using foreign IT project management applications in Hong Kong.

Table 4.3: Suggested solution for overcoming barriers to implement IT in construction project

Solutions	Rate of agreement
Strong local customer services, support and training	83%
Customized application and service	67%
Supporting staff from the IT provider with Adequate local construction knowledge	67%
Provide IT application that does not require too many changes to the existing workflow	100%
Provide IT application that does not require too much learning	100%
Provide IT application with Chinese interface	33%
Standardization of IT tools, platform and digital formats	67%

4.4.2 Learning Curve and User Acceptance

This section discusses questionnaire survey respondents' acceptance and learning requirement on using the VHBuild™ system.

Basically people that can handle Microsoft Windows and Internet browser can use VHBuild™ system fairly well. As shown in table 4.4 all questionnaire survey respondents are familiar with Microsoft Windows and Internet tools. Except for the training of using VHBuild™ system's functions, no other training is needed to be provided for the users. For those applications like office tools, scheduling tools and CAD tools, users just need to know how to read the respective documents.

Table 4.4: Applications that questionnaire survey respondents are familiar with

Applications	Rate of response
Microsoft Windows	100%
Office tools	83%
Internet tools	100%
Scheduling tools	67%
CAD tools	17%

Because of the ease of use of the VHBuild™ system, the questionnaire survey respondents presented that the time for them to familiarize with the operations of VHBuild™ system is usually within 1 week, as shown in Figure 4.5. All of the questionnaire survey respondents confirmed that they can become familiar with the system in 2 weeks.

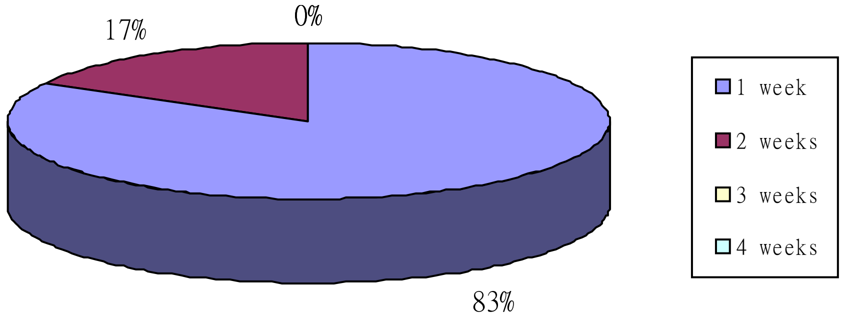


Figure 4.5: Time required for familiarizing with the VHBuild™ system

In order to utilize the VHBuild™ system more smoothly, some extra resources are required. Table 4.5 shows that 100% of the questionnaire survey respondents think that high-speed bandwidth Internet connection is necessary. This is due to the requirement for transmitting vast amounts of documents and information, especially Web camera images. Another highly demanding hardware item is a high performance personal computer, the document scanner and the digital camera. Dedicated technical and supporting staff is recommended for supporting the senior management staff to use the VHBuild™ system.

Table 4.5: Resources required for smooth operation of VHBuild™ system

Resources	**Rate of agreement**
Dedicated technical and supporting staff	33%
High bandwidth Internet connection	100%
Desktop PC with higher performance	83%
Document scanner	66%
Digital camera	83%

4.5 Benefits and Saving

This section presents results derived from the same survey in the above section.

4.5.1 Project Communications and Collaboration

From the 1960s to the 1990s a succession of UK government-sponsored thesiss has exhorted the construction industry to 'work better together' in order to improve its productivity and performance. A thesis in Hong Kong also urged the same thing. A major issue that was seen to be needed to address and solve was how to cope with and effectively exchange the vast amounts of information created during the course of a project. This was effectively directing the efforts to the use of emerging information technology tools. From our questionnaire survey, 100% of the respondents think that the communication channel between different parties in the construction project needs improvement. Figure 4.6 illustrates the survey finding.

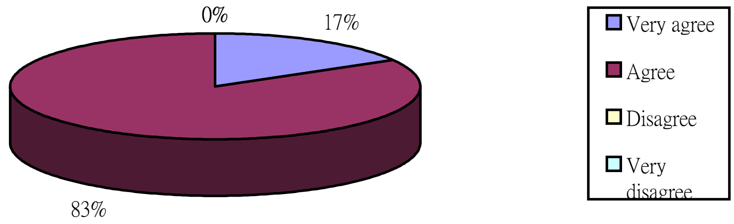


Figure 4.6: Opinions on the need for improving communication channel

It has been widely recognized that the flow of information between the key members of a construction project team is critically important for project success. Dealing with project information, including retrieving, sending and receiving information, occupies a large proportion of the time of those people with important business and project managerial responsibilities.

It is beneficial to both head office and the site supervisor that there is an efficient two-way communication to show how work is progressing; what problems have developed; what information is required to ensure continuity of flow of work; what materials and equipment are required to maintain progress, etc. Most of the communication flows from site to the head office because the vast amount of data collected for progress thesiss and other site related issues, while the remainder is to keep the management informed of every reasonable detail so that they are as well placed to deal with an emergency as the site supervisor. The more efficient is the communication channel, the earlier is the detection of possible problems and the more likely the project will be completed on time and within budget.

In our questionnaire survey, the respondents' time required and handling method for circulation of documents, coordination of design conflicts, and processing of site queries with and without using the VHBuild™ system are captured. The average times for the above three tasks are shown in Figure 4.7. It is found that using the VHBuild™ system can cut the times by more than half.

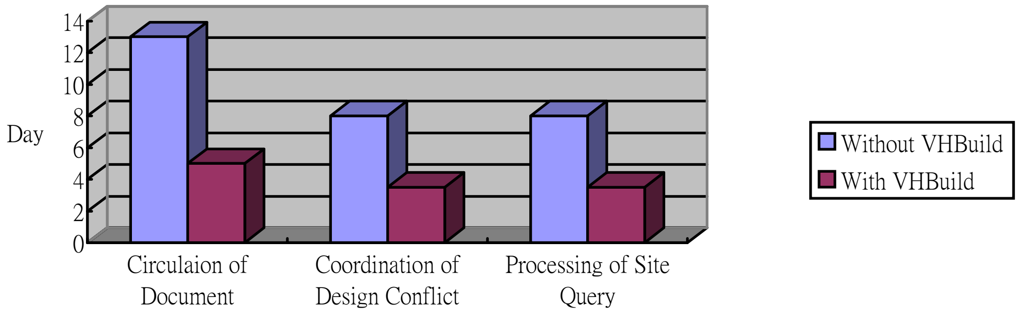


Figure 4.7: Average time required for specific tasks

The reason for the longer times required in the traditional project management practices is the difference in information delivery. Paper-based document system is used in the traditional practices. According to the answer of the questionnaire survey respondents, circulation of documents is by mailing hard copies, which can be time consuming. Tracking of circulation is usually by referring to the received signed hard copies from other project participants. With the VHBuild™ system the interviewees can upload soft copy of documents to a central system and these documents become retrievable instantly from the Web browser through the Internet. The circulation and tracking functions provided in the VHBuild™ system make circulation and tracking of documents a simple 'click and view' job. 100% of the questionnaire survey respondents agree that the site query and drawing circulation function of VHBuild™ can improve the efficiency of the communications, as shown in table 4.6. Benefits of online tracking of documents are also recognized by most of the questionnaire survey respondents. Thus, by utilizing the VHBuild™ system, resources for copying and mailing hard copies, and time spent in tracking of response are saved. More importantly the whole communication cycle is reduced and collaboration of project participants become more efficient.

Table 4.6, Questionnaire survey respondents' response on VHBuild's ability to improve communication efficiency

VHBuild™ Functions	Rate of agreement
Online circulation of site query.	100%
On line circulation of site query answer.	100%
Online tracking of site query status.	83%
Online access of drawing files.	83%
Online access and editing of remark on drawings.	67%
Online circulation of drawings and remarks.	100%

4.5.2 Site Monitoring and Quality Control

Project participants monitor site activities by accessing information captured from site visits, site photos and site daily thesiss. According to the questionnaire survey respondents' answers, when the client's project team wants to inspect and approve a finishing interface or any special events of a particular site location, they will firstly refer to the site photos and other related documents available to them. If information from the site photos and documents is not enough for making judgments, they will go for a site visit. However, according to the questionnaire's findings, the latest copy of site photos takes 1 to 2 weeks to deliver to the client's project team. Instant availability of digital photos on the Web becomes very useful in this situation. Table 4.7 shows that all questionnaire survey respondents agree that instant upload and access of photos can improve efficiency of inspection and approval of finishing interface or any specific events in a particular site location. Other functions, such as the instant upload and access of query sheets, are also recognized by most of the questionnaire survey respondents as helpful for improving efficiency. With the instant availability of site photos, the client's project team can access the latest site conditions remotely and thus can save time for site visits provided that the photos are good enough to show the necessary information.

Table 4.7: Questionnaire survey respondents' response on VHBuild's ability to improve efficiency of inspection and approval of finishing interface or any special event in a particular site location

Functions	**Rate of agreement**
Instant upload and access of query sheet of the event.	83%
Instant upload and access of voice note of the event.	33%
Instant upload and access of photo of the event.	100%
Instant upload and access of video of the event.	50%

From the results of the questionnaire survey, it is found that the site office staff and the head office staff have different views on the adequacy of control mechanism for monitoring tasks. Figure 4.8 to Figure 4.10 show questionnaire survey respondents' opinion on the adequacy of control mechanism for monitoring construction work progress, safety and quality respectively. In the Figures higher scores represent enough control while lower scores represent insufficient control. The questionnaire survey respondents' opinions on the control mechanism for monitoring construction work progress are quite similar, from quite enough to enough. However their opinions on the control mechanism for monitoring safety and quality are different. Score 2 is given by the site staff which include the Clerk of Works, Site Agent and Deputy Site Agent while score 3 and 4 are given by the head office staff. The difference in opinions may due to their different responsibility on those tasks and their different requirements on the control mechanism.

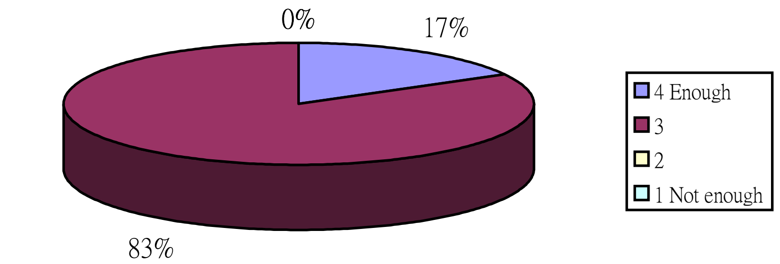


Figure 4.8: Respondents' opinion on adequacy of control mechanism for monitoring of construction work progress

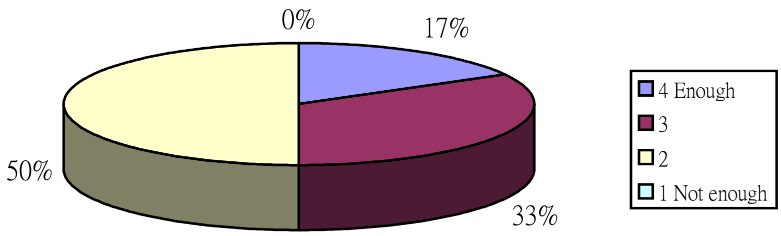


Figure 4.9: Respondents' opinion on adequacy of control mechanism for monitoring of safety

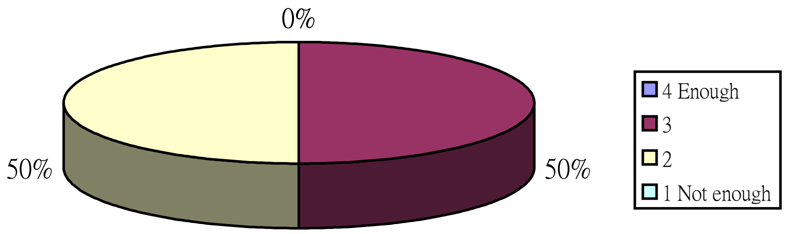


Figure 4.10: Respondents' opinion on adequacy of control mechanism for monitoring of quality

It is found that the VHBuild™ system offers four functions for monitoring construction work progress, safety and quality. These functions help project participants to get a clearer picture of site activities. As shown in table 4.8, these functions are 1) online access of updated general project information, 2) Web camera access to site activities, 3) instant availability of latest site progress photos, and 4) instant availability of site daily thesiss. Most of the questionnaire survey respondents agree that functions 1 to 3 can help them get a clearer picture of site activities while only 50% of the questionnaire survey respondents agree that function 4 is helpful to them. This 50% respondents are from all the site staff. Again the difference in their opinions is due to their different job duties. According to the answers from the Clerk of Works, the latest site daily thesis was received in 3 to 5 days without using the VHBuild™ system. In the Tseung Kwan O project the Clerk of Works can view the latest site daily thesis online in the next day, this allows him to have earlier reference on site activities progress and any special or emergent events.

Table 4.8: Questionnaire survey respondents' response on VHBuild's ability to help them get a clearer picture of site activities

Functions	Rate of agreement
Online access of updated general project information.	83%
Web camera access to site activities.	83%
Instant available of latest site progress photos.	100%
Instant available of site daily thesis.	50%

4.5.3 Project Information Management

Dealing with information can be time consuming. It is important to have an efficient information management system so that the project participants will not waste too much of their time in managing information. Figure 4.11 to Figure 4.14 show the questionnaire survey respondents' opinions on the efficiency of their existing information management system (i.e. before using the VHBuild™ system). Higher score in the Figures represents higher efficiency. The average scores for information circulation, retrieving and searching are 2.17, 2.5 and 2.17 respectively, which indicate that the efficiency of these information management functions is below average acceptable level. The scores for tracking of information delivery is 2, which indicates that this information management function is not sufficient.

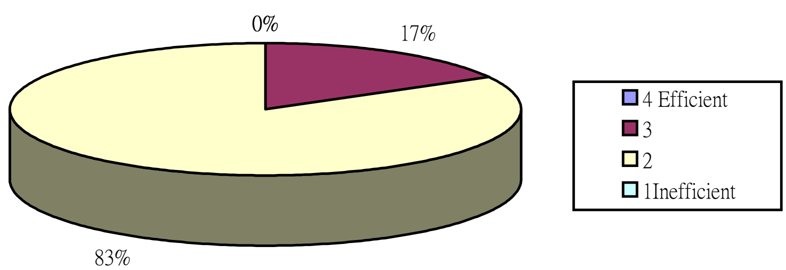


Figure 4.11: Respondents' opinion on efficiency of information circulation

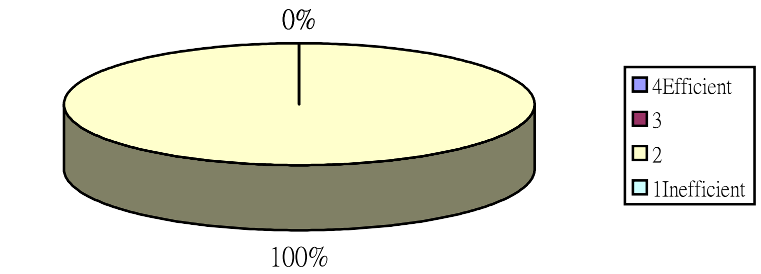


Figure 4.12: Respondents' opinion on efficiency of tracking of information delivery

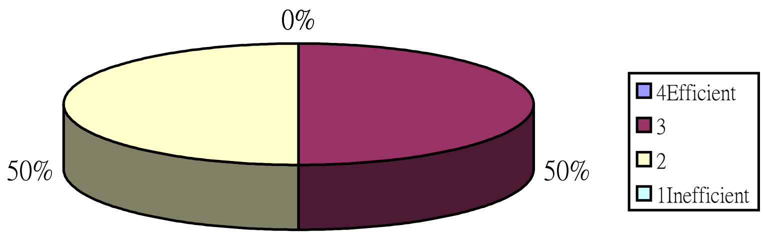


Figure 4.13: Respondents' opinion on efficiency of information retrieving

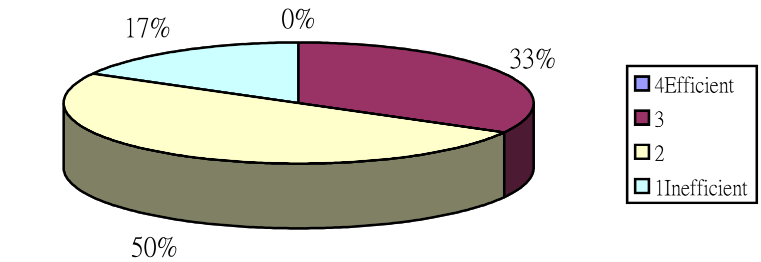


Figure 4.14: Respondents' opinion on efficiency of information searching

The VHBuild™ system provides a systematic central storage of all project documents and allows online retrieving, circulation and delivery tracking of documents. In the Tseung Kwan O project, the users can search for documents such as site meeting records, COW thesiss, BSI thesiss, contractor thesiss, site directions, inspection records, project programme and daily thesiss in the VHBuild™ system in 10 to 15 minutes. Substantial amounts of the project participants' time are saved when comparing with their previous practices for performing those tasks, which require around 1 to 2 days for each tasks. In addition the online delivery of document function shorten the time for receiving documents from other project participants.

Figure 4.15 shows the difference in time required for receiving different types of documents before and after using the VHBuild™ system.

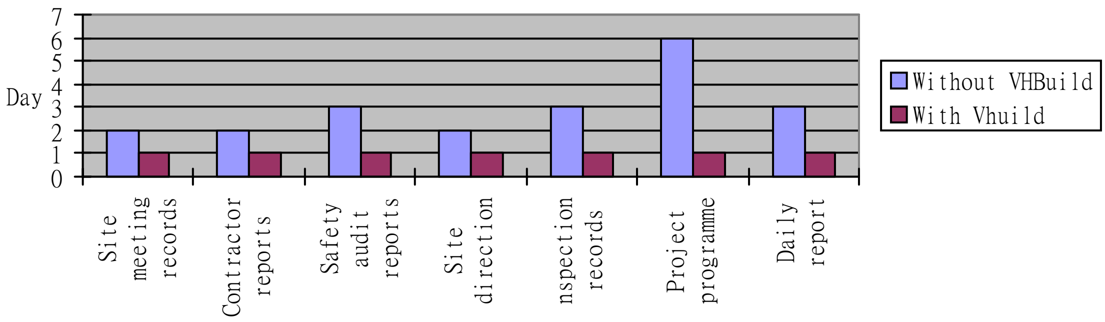


Figure 4.15: Time difference in receiving documents with and without using the VHBuild™ system

4.5.4 Paper Saving

In the Tseung Kwan O project, copies of documents are not sent in hard copies. Instead project participants receive their copies through the VHBuild™ system's online circulation and delivery of documents functions. Table 4.9 shows the number of hard copies of different documents saved in the Tseung Kwan O project.

Table 4.9: Number of copy of documents saved in Tseung Kwan O project

Documents	No. of Copy
Safety plans	5
Safety thesiss	2
Sample submissions	3
Query sheets	6
Site memos	4
Site directions	3
A.I./S.I.	10
Master programme	5
Progress reports	10
Test results	2
Shop drawings	2
Working drawings	5
Standard drawings	5

The actual amount of paper saving may vary in different projects but the saving can be substantial if all copies of the documents are circulated online instead of sending the hard copies.

4.6 Summary

This chapter introduced the application of information management system in construction project management. Problems of existing construction project management practices are identified and functions of project information management system that address business needs of the construction industry are introduced. Barriers in adopting project information management system are then discussed and finally the benefits and saving in adopting this system are illustrated.

Chapter 5: Application of integrated GPS & GIS technology for reducing construction waste and improving construction efficiency

5.1 Introduction

It is generally concerned that urban development directly leads to the increase of construction and demolition waste. Since 1970s, governments, practitioners, and academics have been advancing gradually in pursuance of efficient and cost-effective environmental management to reduce construction waste in a worldwide scope (Chen et al. 2003), however, the total amount of construction waste is still out of control due to massive urban development projects and the lack of effective tools in managing construction wastes. For example, in Hong Kong sevral thousand tons of C&D waste are disposed of at landfills everyday on average (EPD 1999, 2000, 2001, 2002) As a pressing issue in the construction industry, minimizing construction waste has been dealt with through process reengineering, technique innovation and deployment of information technology. For example, Fishbein (1989) and Coventry *et al.* (1999) established a set of construction waste prevention strategies focusing on the effective coordination of materials management, including efficient purchase and ordering of materials, just-in-time delivery, careful storage and the use of materials to minimize loss, maximization of reuse, prevention of undoing and redoing, and reduction of packaging waste.

In addition, Chen et al. (2002) presents a crew-based incentive reward program (IRP) by using a barcode system to reduce any avoidable wastes through rewarding workers according to the amounts and values of materials they saved from their operations. The IRP-based barcode system can provide instant and up-to-date information on the quantities of materials requested or returned by a crew to a storage keeper on site. Specifically, the barcode system can automatically track real-time data of new materials, material residuals, material/ equipment packing, and waste and debris on the site.

However, as the IRP-based barcode system requires that all data related to materials and equipments coming in and out of the storage are manually entered, the use of the system can be time-consuming and fallacious. In order to overcome this problem, this study investigates the integration of the IRP-based barcode system with the Global Position System (GPS), the Geographical Information System (GIS), and the WAN technology to facilitate M&E

management, to control and reduce construction wastes and to increase the efficiency of onsite M&E management.

5.2 Integration of crew IRP-based barcode system with GIS/GPS

5.2.1 Crew IPR-based barcode system

Previous research showed that the skill and attitude of workers are the main factors affecting the amounts of waste generated by workers; particularly workers' attitude toward work, including their enthusiasm and collectivism, is the most important in terms of waste generation (Stukhart 1995). In addition, site surveys (Poon and Ng 1999) also indicated that workers' attitude towards construction operations and materials can make a significant difference to the amount of construction waste generated, as workers may become careless in handling construction materials if there were lack of careful control and rewarding systems. As a result, reusable materials such as reinforcement bars, half-bags of cement, nails and timber pieces, *etc*. are often thrown away around the site. I developed the crew-based IRP thereafter in order to meet the demand of on-site construction material management, and to encourage workers to handle construction materials carefully and efficiently by rewarding them according to their good performances in saving materials through reducing operational mistakes, returning unused materials for reuse or recycle (Chen et al. 2002). The crew IRP was developed based on Maslow's motivation theory (Maslow et al.1998).

The mechanism behind the crew IPR is further illustrated in Equation 1. In Equation 1, for a particular type of material *i*, the performance of crew *j* in terms of material wastage can be measured by $\Delta Q_i(j)$, and at the end of the project, the overall performance of crew *j* can be rewarded in agreement with the $C_i(j)$. This means that the IRP is implemented according to the amount of materials saved or wasted by a crew. For example, if a crew saved materials ($\Delta Q_i(j)>0$), the project manager may then award the crew a bonus based on the amount of $C_i(j)$. In Equation 1, the value of $Q_i(j)_{es}$ has to be carefully decided according to the circumstances of construction projects and previous experience (Schuette and Liska 994, CIOB 1997). In order to increase the precision in reward through computation, a knowledge-driven system was introduced to reuse CM knowledge to more accurately define the value of $Q_i(j)_{es}$ (Chen et al.2004).

$$C_i(j) = \sum_n \Delta Q_i(j) \times P_i = \sum_n (Q_i(j)_{es} - (Q_i(j)_{de} - Q_i(j)_{re})) \times P_i \quad (1)$$

Where,

$C_i(j)$	=	The total amount of material *i* saved (if it is positive) or wasted (if it is negative) by crew *j*;
$\Delta Q_i(j)$	=	The extra amount of material *i* saved (a positive value) or wasted (a negative value) by crew *j*;
P_i	=	The unit price for material *i*;
$Q_i(j)_{es}$	=	The estimated quantity that includes the statistic amount of normal wastage;
$Q_i(j)_{de}$	=	The total quantity of material *i* requested by crew *j*;
$Q_i(j)_{re}$	=	The quantity of unused construction materials returned to the storage by crew *j*;
i	=	Number of any construction materials that may be requested by a crew.
j	=	Number of any construction crews whose operations may potentially generate waste.
n	=	The total number of tasks in the project that need to use material *i*.

Figure 5.1 illustrates the architecture of the crew IRP-based barcode system.

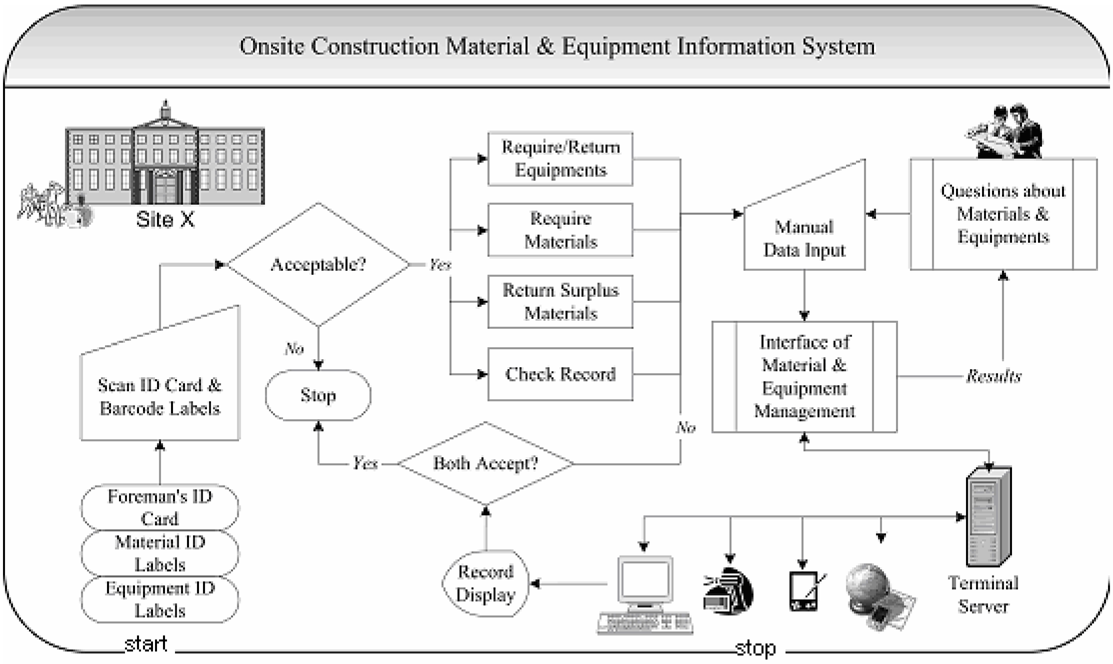


Figure 5.1: A conceptual model for the crew IRP-based barcode system.

The hardware system of the crew IRP-based system includes an on-site terminal computer server system, and barcode laser scanners. Table 5.1 lists an example of the hardware and software components of a crew IRP-based system application.

Table 5.1: An example of crew IRP-based system application

Hardware	Software
- Dell® Dimension® 4100 desktop	- Microsoft® Windows® NT/XP
- PSC QuickScan® 5385 scanner with keyboard wedge type of decoder	- Microsoft® Office® XP
- Handbook of barcode labels for construction M&E (*internal*)	- Loftware® Label Manager

In this application example, barcode representation adopted is the Code 128 symbology (Stukhart 1995) by using Loftware® Label Manager to design the identification labels, and all bar-coding labels are printed out through a HP LaserJet printer. For each material and equipment, one bar-coding label is designed to represent one corresponding material or equipment and its relevant information. For examples, the code *0002-525-1-X* represents "Cement - Portland, Ordinary 525# - 1 standard bag - Trademark X", and the code *0201-003-1-Y* represents "Aggregates - 3 mm particle diameter - 1 cubic meter - Provenance Y" (Chen et al. 2002). For each crew, one bar-coding label is designed to represent one crew; for example, coding number *586-01-0208-010* represents "Concretor crew 586 and its leader's staff ID number is 01-0208-010". By scanning the barcodes for materials and crews, the computer system keeps records of materials used or returned by the crew. All these records are further used to calculate the possible wastes from each crew. Experimental results indicated that there are about 10% material saving by implementing the crew IRP-based barcode system (Chen et al. 2002).

5.2.2 GPS/GIS applications in construction

GIS is a computer-based system to collect, store, integrate, manipulate, analyze & display data in a spatially referenced environment, which assists to analyze data visually and see patterns, trends, and relationships that might not be visible in tabular or written form (EPA2 2004). The application areas of GIS technology for environmental management include site remediation, natural resources management, waste management, groundwater modeling, environmental impact assessment, policy assessment compliance permit tracking, and vegetation mapping etc (EPA2 2004). On the other hand, GPS is a satellite-based navigation system made up of a network of approximately 24 satellites, which were placed into orbit by the U.S. Department of Defense in 1970s and circle the earth twice a day in a very precise orbit and transmit signal information to earth where GPS receivers take this information and use triangulation to calculate the user's exact location (EPA2 2004).

The application areas of GPS technology for civilian utilization include public safety, emergency location, automobile navigation, vehicle tracking, airport surveillance, control surveys, radial surveys, site acquisition & surveying, digital network timing & synchronization, precision farming, farm vehicle automation, and field environmental decision support etc (EPA1 2004, Bossler 2001, Kennedy 2002). In addition to the separated use of GPS technology or GIS technology in the mentioned areas, the integrated utilization of

GPS and GIS technology for civilian purpose has also increased since 1990s (EPA1 2004, Hampton 2004).

In the fields of construction, both GPS technology and GIS technology and their integrated technology have been introduced synchronously to the many areas such as transportation management, facility delivery, urban planning, jobsite safety monitoring, site layout and development, and business analysis etc (Hampton 2004, Li et al. 2003). In addition, most previous research and development focused on a single application of GPS technology or GIS technology, and the benefits of integrated GPS and GIS technology, which can bring high efficient and cost-effective results to construction sectors, are still under excavation.

In addition, the integrated GPS and GIS technology has been used to provide the decision-makers with the internal capability for rapid and effective contaminated site characterization (EPA1 2004), which is a typical utilization of the integrated technology in the area of environmental management to monitor and control adverse environmental impacts such as hazardous waste and noise. However, no research is reported on applying the integrated technology to minimize adverse environmental impacts in construction such as construction waste and construction noise on sites.

5.2.3 Enterprise-wide crew IRP-based barcode system

The enterprise-wide crew IRP-based barcode system is an expansion of the crew IRP-based barcode system, as indicated in Figure 5.2. The aim is to implement the IRP-based barcode system over all construction sites within a company. Within this system, IRP-based barcode systems on different construction sites are connected through a company Intranet. M&E data of all construction sites are aggregated so that top management in the company can enhance the efficiency of utilizing M&E information throughout the headquarters and site management offices of a construction company Site managers are able to get real-time information of M&E within the enterprise so as to make any further decisions depending on information such as implementation of crew IRP in each project and the deployment of M&E among all projects. In addition, the enterprise-wide crew IRP-based barcode system is an effective addition to a general-purpose construction project management system or an ERP system for a construction company. Figure 5.1 illustrates the on-site section of an enterprise-wide crew IRP-based barcode system, the entire section of the proposed system is presented in Figure 5.2. Considering the possibility of M&E data input at the headquarters, the component of crew IRP-based barcode system is combined to a construction project management system.

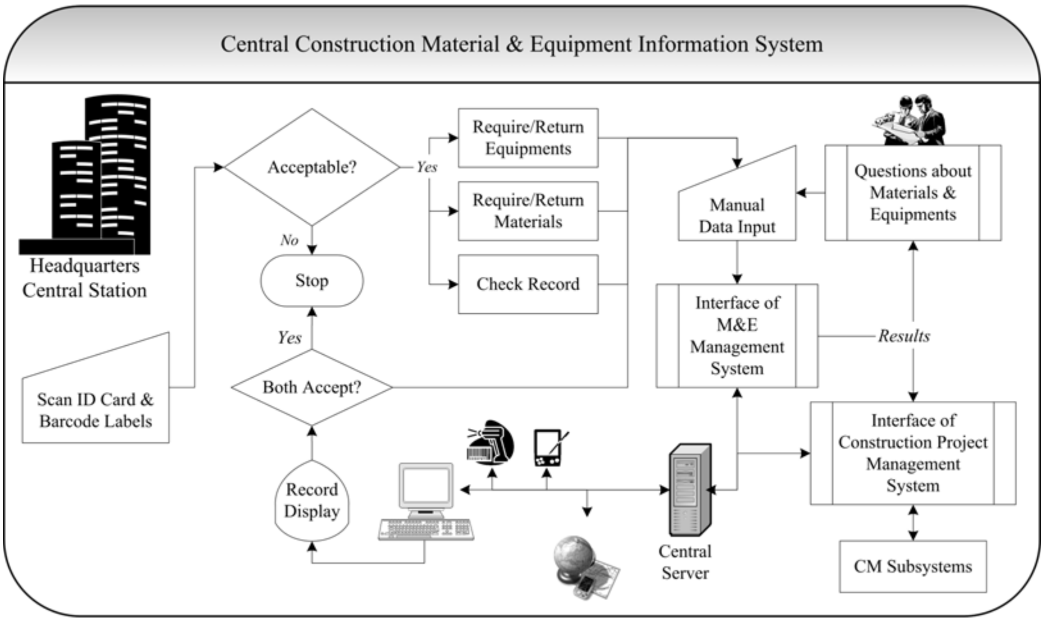


Figure 5.2: A conceptual model for the enterprise-wide crew IRP-based barcode system.

The data transfer among each on-site M&E system to the central M&E system and construction project management system requires physical support from WAN. There are two main types of data:

1. Data from construction sites, including
   - storage condition of M&E in each individual construction site,
   - demand of M&E from individual construction site,
   - report of crew IRP from individual construction site, and
   - query and pivot of M&E to other construction sites and the headquarters; and
2. Data from headquarters, including
   - query and pivot of M&E storage condition on each construction site,
   - query and pivot of M&E demand from each construction site, and
   - demand of M&E deployments among each construction site.

All these data transfer can be realized within a typical management information system. Real-time communication among the headquarters and each construction site can be achieved based on the WAN. However, with the requirements of dynamic construction project management, the function and structure of traditional management information system cannot provide satisfied services in terms of real-time queries. For example, if managers from the headquarters want to obtain information related to certain kind of material, such as queries on the present location of the material and its arrival time to a specific construction site; project information management systems without GIS/GPS will not be able to provide answers to such queries.

5.2.4 GPS & GIS integrated M&E management system

The integrated GPS and GIS technology is to build new capacity such as construction vehicles tracking to the traditional M&E management information system. The purpose is to transfer real-time location information of construction M&E being carried to a construction site. Integrated GPS and GIS technology helps to improve efficiency and to increase profits by providing real-time vehicles locations & status reports, navigation assistance, drive speed & heading information, and route history collection [22]. Figure 5.4 illustrates the simple architecture of the integrated GPS and GIS technology for a M&E management system to reduce construction waste.

In this study, inter-city freight transportation of M&E is concerned (see Figure 5.4), including waterway transportation, air transportation, and overland transportation such as transportations by railway and highway. Cargoes are fitted with GPS, which can transmit its positional data together with attribute information to the central station at headquarter and distributed terminals on construction sites via the WAN. The central station at headquarter is a monitoring station, where the accurate position of each construction cargo is displayed on a GIS map, and the information of each cargo can be queried. By using functions in a GIS system, the central station can get the current location of a cargo and estimate the travel time of a cargo before it arrives at a predetermined construction site. Moreover, the central station also can send command to drivers via Personal Digital Assistant (PDA) to dispatch the cargoes transportation such as when they should start or which route they should select. This is very helpful for construction projects especially in regions such as Hong Kong where the space for material storage on a construction site is very limited.

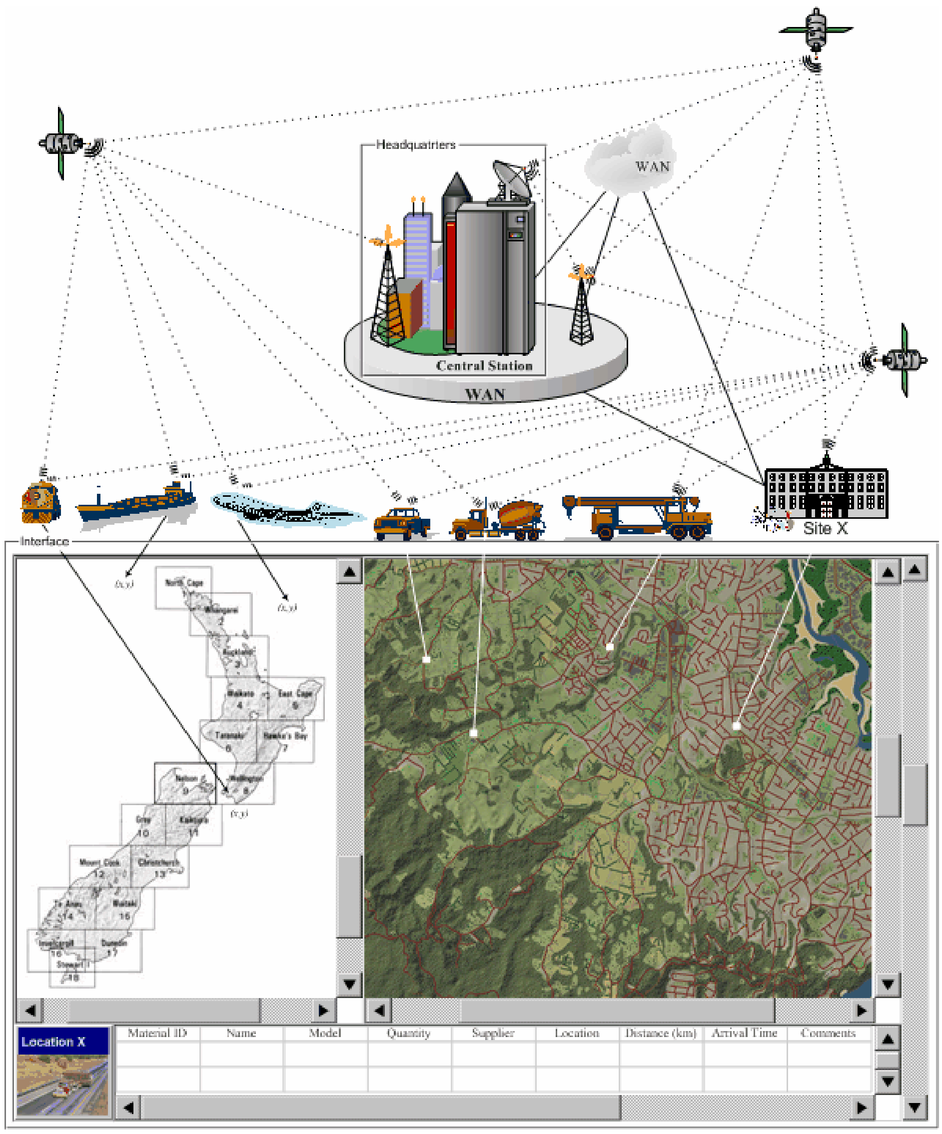


Figure.5.3: A conceptual model of GPS & GIS integrated M&E management system.

The deployment of the GPS and GIS integrated construction M&E management system requires physical supports from computer hardware and software systems. The software system includes GPS software, GIS software, and the crew IRP-based M&E management system. In our study, the GIS software is ArcGIS series from ESRI (Environmental Systems Research Institute, of Redlands, California, USA), and the GPS software is GeoExplorer series from Trimble, which is an integrated collection of GIS-oriented GPS software products for advanced GPS/GIS data collection and mobile GIS tools, including Office Software **(**GPS Pathfinder Office and Trimble GPS Analyst extension for ArcGIS), and Field Software **(**TerraSync, GPScorrect for ESRI ArcPad, and GPS Pathfinder Tools Software Development Kit (SDK)**)** [22]. On the other hand, the hardware system includes enterprise-level computer server for control at central station, distributed computer desktop for operations on construction sites, notebook computers, Pocket PC and handhelds for communications on the road.

The hardware and software configuration adopted in this study are listed in Table 5.2.

Table 5.2: Hardware and software configuration adopted in the integrated construction M&E management system application

Hardware	Software
- Dell® Precision™ WS 370/670 (desktop)/ M60 (mobile) workstation	- Microsoft® Windows® Server 2003 SE
- Dell® PowerEdge™ 6600 (enterprise-level) server	- Microsoft® Windows® NT/2000/XP/CE
- Trimble® GeoExplorer® series handhelds	- Microsoft® Pocket PC
- PSC QuickScan® 5385 scanner with keyboard wedge type of decoder	- Microsoft® Office® XP
- Handbook of barcode labels for construction M&E (*internal*)	- Loftware® Label Manager
	- ESRI® ArcGIS® series
	- Trimble® GeoExplorer® series

5.3. Case study

5.3.1 Problem

The C&D waste has been identified as a priority waste in the New Zealand Waste Strategy because of its quantity and complexity. The New Zealand government sets a target of 50% waste being disposed of to landfills by 2008, and requires local authorities to put in place programmes for monitoring C&D waste quantities (MFE 2004). Under this circumstance, a Hong Kong based construction company had an ongoing project in Auckland, New Zealand (see Figure 5.4), and the senior managers at headquarter in Hong Kong wanted to deploy all construction M&E by using the GPS and GIS integrated construction project management system, and to implement the crew IRP on the construction site at Auckland to fulfill company's environmental promise in minimizing construction waste.

Among the construction M&E required in this project, most of them are delivered from Australia and China, and only a small number of M&E are ordered from local suppliers in New Zealand. In order to carry out the construction project on time with minimum generation of wastes, site managers asked the headquarter to provide accurate arrival time of construction M&E so as to deal with limitations of M&E storage on site.

5.3.2 Requirements specification

As managers from both the headquarter and construction site need dynamic and accurate location information of M&E to carry their jobs effectively, the demand for immediate response and tight command and control necessitates the GPS and GIS integrated solution to enable real-time interactive communications for dispatch and navigation, and server-based cargo tracking and messaging. The GPS and GIS integrated construction M&E management system (see Figure 5.4) is to have the following major positioning related requirements from both the headquarter at Hong Kong and the construction site at Auckland:

1. Efficient dispatch and central supervisory control of cargoes among the construction site and the M&E suppliers from China, Australia, New Zealand, and Hong Kong, which means
   - to correctly arrange the departure time and routes of each cargo from suppliers,
   - to accurately define the arrival time of each cargo at the construction site,
   - to actively track the dynamic position of each transportation,
   - to timely monitor and control the process of each transportation from departure to arrival, and
   - to dynamically record any delay due to the transportation by suppliers for claiming indemnity, etc.
2. Efficient dispatch and on-site supervisory control of cargoes on the road and M&E on site at the construction site side, which means
   - to dynamically check the location of each cargo on the road to the construction site,
   - to timely communicate with the headquarters about each transportation,
   - to accurately record the arrival time of each cargo on site,
   - to accurately record the details of each cargo arrived on site, and
   - to accurately record the details of each material or equipment received by each craw, etc.

The headquarter at Hong Kong chose the outlined commercial solutions from Microsoft, Loftware, ESRI and Trimble (see Table 5.4) to provide integrated GPS and GIS capabilities for managers on both sides for dynamic construction M&E management. There were two phases to deploy the application. In Phase I, proposed GPS and GIS devices including software system and hardware system were built into the current construction M&E management system, which was integrated into a M&E subsystem. Detailed GPS coordinate information, including extensive map as well as latitude, longitude, date and time could be displayed in the system. The enhanced system was modified to interface with the headquarter's existing construction project information management system. In Phase II, Trimble External Patch Antenna (EPA) was adhered to each cargo on the road to the construction site as a location tracking device. The Trimble EPA was specially designed for seamless integration with Trimble GeoExplorer series handhelds and the WAN infrastructure, and is ideal for use in all environments where a high yield of positions is required [22]. By automatically positioning each transportation, real-time information of each cargo was accessible by both central and on-site managers.

5.3.3 Results

Managers from both the headquarter in Hong Kong and the construction site in Auckland were satisfied with the application of integrated GPS and GIS technology in construction management. Table 5.3 provides a comparison of the non-integrated system versus the GPS&GIS integrated system for the construction M&E management solution. According to the comparison, the GPS and GIS integrated solution improved the construction efficiency through increasing the effective working hour of construction equipments and reducing construction duration and thus the cost of workforce. Due to the initial investment to the hardware and software systems, initial costs increased compared with the former non-integrated system. However, the costs will decrease with the further utilization of the system.

Table 5.3: Comparison of the non-integrated system versus the GPS&GIS integrated system

Parameter	Non-integrated system	Integrated system	Variation
Hardware cost	$2,500	$8,000	↑220%
Software cost	$1,200	$6,000	↑400%
Equipments utility	3,100 hours	3,600 hours	↑16%
Construction duration	210 days	195 days	↓7%
Workforce cost	$400,000	$360,000	↓10%
Construction waste	$8,500	$2,000	↓77%

5.4. Conclusions and Recommendations

This chapter aims to enhance the crew IRP-based barcode system for construction M&E management by utilizing integrated the GPS and GIS technology. By integrating GIS/GPS with the crew IRP-based barcode system, real-time information on location, quantities and types of materials are recorded into the computer system. In order to achieve this objective, the former project-oriented crew IRP-based barcode system was first extended to an enterprise-wide construction M&E management system with an integration to the traditional construction project management system. The extended prototype was further developed to a GPS and GIS integrated construction M&E management system in respect that managers from both headquarters and construction sites have the need to get real-time information to control cargoes on the road to sites and to reduce the waste generation on sites. The author of this chapter then present the conceptual model for the proposed GPS and GIS integrated system with its logical system design and the system implementation. Potential requirements and further applications are discussed as well. Finally, a case study is conducted to demonstrate the cost benefit of the novel system in construction. It is expected that the proposed innovation, which changes the M&E management from process-focused partial waste prevention to project-oriented total waste reduction, can dramatically improve the serviceability of barcode system in real-time data capture and reuse to assist the ERP implementation of construction sectors.

Chapter 6 Conclusions and Recommendations

This thesis presents several potential qualified IT applications in the innovative construction project management based on a comprehensive literature review related to the research and development of IT in the construction industry, and the evaluation result from the ANP decision-making model. The IT applications, including e-commence system for procurement of construction material and equipment, bar-coding system for construction material and equipment management on site, construction project management system for documentary management, and GPS&GIS integrated system for managing construction sites are remote locations, are the primary means of IT solutions for innovative construction project management.

6.1 Contributions of this thesis

The focus of this research is to identify and evaluate a framework to provide an overall support the information flow of the project procurement process. In developing such a framework, the study adopted the following principle: the strength of a chain is dependent on its weakest element. In other words, this study advocates that stand-alone applications of IT to the project procurement process are not efficient and effective. Instead, there is a need for an overall framework to guide the application of IT to support the project procurement process.

The uniqueness of the thesis is reflected at two aspects. First, it identified and evaluated a number of information technologies that can be applied to support various stages of the project procurement process. Second, the study developed a framework which can provide some guidance for applying IT in supporting project procurement process.

Specifically, various issues related to the application of E-commerce systems to construction material procurement have been discussed and a prototype of construction e-commerce has been developed and tested. The application of barcode system for monitoring construction material flow on site has proven to be efficient and effective in minimizing avoidable wastes. A case of the VHBuild, a Web-based project management system, exhibited the benefits of using such a system in managing construction projects. However, the case study also revealed many difficulties and challenges in applying such technology in construction. The application of GPS&GIS integrated system for managing construction projects at remote sites make use of the advantages of GIS and GPS technologies in information capture and exchange. The combined use of all these information technologies forms the basis of the overall framework for supporting the information flow of a project procurement process.

6.2 Recommendations for further R&D

This study has explored the feasibility of integrating several mature technologies to support the information flow of the project procurement process. The individual technology, and its applicability to specific aspect of the project procurement process, have been discussed and evaluated. However, many issues remain unsolved. For example, the study does not explore how data/information can be share among different information technologies explored in the study. As another example, the study does not evaluate the framework through a single project, as the individual technologies were evaluated through different projects. These should be further studied in order to improve the acceptance and usefulness of the framework developed in this study.

References

AGC (1996). *Reader Profile: Constructor Readers Are Your Best and Future Customers*. Constructor Magazine. The Associated General Contractors (AGC) of America. Retrieved in July 2003 at http://www.agc.org/content/public/NewsBulletins/reader_profile.inc

Anderson, M. R. (1993). Barcodes bring savings. *ENR*. November 29. 45.

Andreoli J. M., Pacull, F., and Pareschi, R., (1997). XPECT: a framework for electronic commerce, *IEEE Internet Computing*, July-August, 40-48.

Applegate L. M., McFarlan J.W., and McKenny J. L. (1999). *Corporate Information Systems Management*, 5th ed., Irwin-McGraw-Hill, New York, USA.

Bakos J. Y., (1991). A strategic analysis of electronic marketplaces, *MIS Quarterly*, **15**(3), 295-310.

Bershad, B. N., Savage, S., Pardyak, P., Sirer, E.G., Fiuczynski, M. E., Becker, D., Chambers, C., and Eggers, S. (1995). Extensibility, Safety and Performance in the Spin Operating System, *Proceedings of the 15th Symposium on Operating System Principles.*

Biehl, I., Meyer, B., and Wetzel, S. (1998). Ensuring the Integrity of Agent-Based Computations by Short Proofs, *Lecture Notes in Computer Science 1477*, Springer. 183-194.

Baldwin, A. N., Thorpe, A., and Alkaabi, J. A. (1994). Improved Materials Management through Bar-Coding: Results and Implications from a Feasibility Study. *Proceedings of Institute of Civil Engineers: Civil Engineering*. Vol. 102, November.156-162.

BCTD (2003). Smarter Skills and Security System: Carding in Construction: How a new smart card credentialing system is ensuring health and safety on construction sites. The Building and Construction Trades Department, AFL-CIO, Washington, DC 20006. Retrieved on 22 July 2003 from http://www.buildingtrades.org/homeindex/smartcard.html

Bell, L. C., and McCullouch, B. G. (1988). Barcode Application in Construction. *Journal of Construction Engineering and Management*. ASCE. 114(2), 263-278.

Bernold, L. E. (1990). Testing Barcode Technology in Construction Environment. *Journal of Construction Engineering and Management*. ASCE. 116(4), 643-655.

Blakey, L. H. (1990). Barcode: Prescription for Precision, Performance, and Productivity. *Journal of Construction Engineering and Management*. ASCE. 116(3), 468-479.

Bossler J D (2001) *Manual of geospatial science and technology*, London; New York: Taylor & Francis, 2001.

Brandon, T. L., and Stadler, R. A. (1991). Use of Barcode Technology to Simplify Sieve Analysis Data Acquisition. *Geotechnical Engineering Congress 1991 (Volume 1): Proceedings of the Congress sponsored by the Geotechnical Engineering Division of the American Society of Civil Engineers*. (Edited by McLean, F. G., Campbell, D. A. and Harris, D. W.) (Geotechnical Special Publication No. 27) ASCE. 556-561.

Cao, J., Chan, G., Jia, W., and Dillon, T. (2001). Checkpointing and Rollback of Wide-area Distributed Applications using Mobile Agents. *Proc. IPDPS 2001*, San Francisco, USA, April, 22-34.

Calvert, R. E. (1995). *Introduction to Building Management*, Butterwoth-Heineman, 6th Edition.

Coventry, S, Woolveridge C, Patel V (1999), *Waste minimisation and recycling in construction* - boardroom handbook. Special Publication 135. CIRIA. London. 1999.
Canter, M. R. (1993). *Resource Management for Construction*, Macmillan Press, UK.

Chen Z, Li H, Wong C.T.C. (2002) An application of bar-code system for reducing construction wastes. *Automation in Construction* 11(5), 521-533.

Chen Z, Li H, Wong C.T.C.(2003), Webfill before landfill: an e-commerce model for waste exchange in Hong Kong. *Journal of Construction Innovation* 3(1) 27-43.

Chen Z, Li H, Hong J (2004), An integrative methodology for environmental management in construction. *Automation in Construction* 13(5) 621-628.

Chess, D., Harrison, C., and Kershenbaum, A. (1995). Mobile Agents: Are They a Good Idea?, *IBM Research Thesis*, RC 19887 (#88465) 3/16/95.

Choudhury, V., and Konsynski, B. (1998). *Inter-Organizational Information Systems and the Role of Intermedíries in Market Channels: A study of Two Industries*, Information Technology and Industrial Competitiveness: HowIT Shapes Competition, Kluwer Academic Publishers, Boston: MA, USA. 67-90.

CIOB (1997) *Code of estimating practice* (6th edition), The Chartered Institute of Building. Longman. England. 1997.

C21 (Construction 21 Steering Committee) (1999) Re-Inventing Construction. Ministry of Manpower and Ministry of National Development, Singapore.

Deloitte & Touche (2000). *Insights in Construction: Fourth Thesis on the Nation's Leading Construction Companies*. A Joint Survey by Deloitte & Touche and The Associated General Contractors of America. Retrieved in July 2003 at http://www.deloitte.com/dtt/cda/doc/content/AGCfinal.pdf

Dulaimi, M. F., Ling, F. Y. Y., and Ofori, G. (2001). Building a World Class Construction Industry: Motivators and Enablers. Department of Building, School of Design and Environment, National University of Singapore. Singapore University Press Ltd. Singapore.

Dasgupta, P., Narasimhan, N., Moser, L. E., and Melliar-Smith, P. M. (1999). MAgNET: Mobile Agents for Networked Electronic Trading, *IEEE Trans. On Knowledge and Data Engineering*, **11**(4), July/Aug, 509-525.

Dijkatra, E. W. (1959). *A note on two problems in connection with graphs*, Numeriche Mathematik, 1, 269-271.

Egan, J. (1998). Re-thinking construction. DERT, London.

Elsworth, J. H., Ellsworth, M. V. (1995). *Marketing on the Internet – Multimedia Strategies for the World Wide Web*, Wiley, New York.

European Commission -Information Society Directorate-General (1999). *Electronic Commerce an Introduction.* Available at http://www.ispo.cec.be/ecommerce/answers/introduction.html.

Feigenbaum, J., and Lee, P. (1997). Trust Management and Proof-Carrying Code in Secure Mobile-Code Applications, *DARPA Workshop on Foundations for Secure Mobile Code*, Monterey, CA, USA, Position Paper.

Fritzinger J. S., Muller M. (1996) *Java Security*. Available at http://www.javasoft.com/securitywhitepapers.

Echeverry, D., Guerra, C. A. and Beltran, A. (1998). A Regional Attempt to Implement Barcode Control in Construction Project. *Computing in Civil Engineering: Proceedings of International Computing Congress in Civil Engineering (5th)* (Editor-in-chief: Wang, K. C. P.; Associate editors: Adams, T., Maher, M. L., and Songer, A.). ASCE. 450-453.

Echeverry, D., and Beltran, A. (1997). Barcode Control of Construction Field Personnel and Construction Materials. *Computing in Civil Engineering: Proceedings of International Computing Congress in Civil Engineering (4th)* (Editor-in-chief: Adams, T. M.). ASCE. 341-347.

Echeverry, D. (1996). Adaptetion of Barcode Technology for Construction Project Control. *Computing in Civil Engineering: Proceedings of International Computing Congress in Civil Engineering (3th)* (Editor-in-chief: Vanegas, J and Chinowsky, P.). ASCE. 1034-1040.

EPA1 (2004) GPS - Global Positioning System. Retrieved on 9 August 2004 from http://www.epa.gov/region5fields/htm/methods/gps/

EPA2 (2004), What is GIS (Geography Information Systems)? Retrieved on 9 August 2004 from http://www.epa.gov/region5fields/htm/methods/gis/

EPD (2002), Environment Hong Kong 2002. Retrieved on 11 August 2004 from http://www.info.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html

EPD (2001), Environment Hong Kong 2001. Retrieved on 11 August 2004 from http://www.info.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html

EPD (2004), Environment Hong Kong 2000. Retrieved on 11 August 2004 from http://www.info.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html

EPD (1999), Environment Hong Kong 1999. Retrieved on 11 August 2004 from http://www.info.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html

Fishbein B K (1998), Building for the future: strategies to reduce construction and demolition waste in municipal projects. (1998) Retrieved on 15 May 2002 from http://www.informinc.org/cdreport.html

Funfrocken, S. (1998). Integrating Java-based Mobile Agents into Web Servers under Secrity Concerns, *Proc. 31st Hawaii Int'l Conf. On System Sciences (HICSS31)*, Kona, Hawaii, Jan., 34-43.

Gek, W. T., Micheal, J. S., and William, F., (2000). *Web-based global supply chain management*, Handbook of Electronic Commerce, Springer. 457-478.

Gray, R. S. (2000). Mobile Agents: Motivations and State-of-the-Art Systems, *Tech. Thesis*, Dept. of Computer Science, Dartmouth College, April 2000. http://agent.cs.dartmouth.edu/.

Greenstein, M., and Feinman, T. M. (2000). Electronic Commerce: Security, Risk Management and Control, McGraw-Hill.

Green, S. (2003). Technology Foresight Thesis: Progress through Partnership (1995). In Construction Thesiss 1944-98. Edited by Murray, M., and Langford, D. (2003). Blackwell Science Ltd. UK. 164-165.

Hagel III J., and Armstrong, A. G. (1997). *Net Gain – Expanding Markets through Virtual Communities*, Harward Business School Press, Boston, MA, USA.

Hampton T (2004) *10 electronic technologies that changed construction* (6/21/2004 Issue), ENR, <http://enr.construction.com/features/technologyEconst/archives/040621.asp>

Haynes, T. (1995) *The Electronic Commerce Dictionary*, Robleda Company, Menlo Park, CA, USA.

Hsieh, W. C., Fiuczynski, M. E., Garrett, C., Becker, D., and Bershad, B. N. (1996). Language Support for Extensible Operating Systems, *Proceedings of the Workshop on Compiler Support for System Software*.

Ho, F. W. H. (2002). Hong Kong as an Information Society. (2002 Edition) Technical Secretariat, Census and Statistics Department, Central Government Offices, Hong Kong Special Administrative Region, China.

Howard, R., Kiviniemi, A. and Samuelson, O. (1998). Surveys of IT in the Construction Industry and Experience of the IT Barometer in Scandinavia. ITcon: Electronic Journal of Information Technology in Construction. Vol.3, 45. Retrieved in July 2003 at http://www.itcon.org/1998/4/paper.pdf

Kalakota, R., and Whinston, A. B. (1996). *Electronic Commerce: A Manager's Guide*, Reading, MA:Addison-Wesley.

Kaufman, F. (1966). Data systems that cross company boundaries. *Harvard Business Review*, May-June. 97-103.

Keller, A. M., and Genesereth, M. R. (1997). Using infomaster to create a housewares virtual catalogs. *The International Journal of Electronic Commerce and Business Media*, 7(4), 41-44.

Kennedy M (2002) *The global positioning system and GIS: an introduction*, London: Taylor & Francis, 2002.

Kosiur, and Daivd, R. (1997). *Understanding Electronic Commerce*, Redmond, Wash: Microsoft Press.

Kemme, M. R. (1998). Barcode Tracking System for Hazardous Waste (HW). Construction Engineering Research Laboratory, US Army Corps of Engineers. Retrieved on 22 July 2003 from http://www.cecer.army.mil/td/tips/product/details.cfm?ID=25&TOP=1

Leung, W. K., and Kwong, M. (2001). Drawing Management System using 2-Dimensional Bar Codes. Proceedings of International Conference on Construction. Held at Hong Kong Convention and Exhibition Centre on 19-21 June. 426-435.

Lundberg, E. J., and Beliveau, Y. J. (1989). Automated Lay-down Yard Control System-ALYC. *Journal of Construction Engineering and Management*. ASCE. 115(4), 535-544.

Lange, D. B., and Oshima, M. (1998). *Programming and Deploying Java Mobile Agents, With Aglets*, Addison Wesley, New York.

Laudon, K. C., and Laudon, J. P. (2000). *anagement Information Systems,* 6th edition, Prentice-Hall, London.

Lee, P., and Necula, G. (1997). Research on Proof-Carrying Code for Mobile-Code Security, *DARPA Workshop on Foundations for Secure Mobile Code*, Monterey, CA, USA, Position Paper.

Li, H., Cao, J., Castro-Lacouture, D., and Skibniewski, M. (2002). A Framework for Developing a Unified B2B E-Trading Construction Marketplace. *Automation in Construction*, 12, 201-21.

Li H, Kong C W, Pang Y C, Shi W Z, Yu L (2003), Internet-Based Geographical Information Systems System for E-Commerce Application in Construction Material Procurement, *Journal of Construction Engineering and Management, ASCE* **129**(6), 689-697.

Liang, T-P., and Huang J-S. (2000). A framework for applying intelligent agents to support electronic trading. *Decision Support Systems* 28(2000), 305-317.

Lincke, D. M. (1998). Evaluating integrated electronic commerce systems. *The International Journal of Electronic Commerce and Business Media*, 8 (1), 7-11.

Lummus, R. P., and Vokurka, R. J. (1999). Managing the demand chain through managing the information flow: capturing the ‘moments of information’, *Production and Inventory Management Journal*, 40(1), 16-20.

Luck, R., McGeorge, D., and Betts, M. (1997). Research Futures: Academic Responses to Industry Challenges. Construction IT Centre of Excellence. UK.

Mandry, T., Pernul, G., and Rohm, A. W. (2001). Mobile Agents in Electronic Markets: Opportunities, Risks, Agent Protection, *International Journal of Electronic Commerce*, 5(2), 47-60.

Marchal, B., Mikula, N. H., Peat, B. and Webber, D. (1998). *XML: Enabling Next-Generation Web Applications,* 5.

Maslow A H, Stephens D C, Maslow G H (1998) *Human Management*. John Wiley, New York. 1998.

McCanne, S., and Jacobson, V. (1993). The bsd Packet Filter: A New Architecture for User-level Packet Capture, *Proceedings of the USENIX Technical Conference*, 259-269.

Marsh, L., Flanagan, R., and Finch, E. (1997). Enabling Technologies: a primer on bar coding for construction. The Chartered Institute of Building. UK.

McCullouch, B. G., and Lueprasert, K. (1994). 2D Barcode Applications in Construction. *Journal of Construction Engineering and Management*. ASCE. 120(4), 739-753.

Mohanty, R. P., and Deshmukh, S. G. (2000). Reengineering of a supply chain management system: a case study, *Production Planning and Control*, 11(1), 90-104.

Mukhopadhyay, T. (1998). *How to win with electronic data interchange*, Information Technology and Industrial Competitiveness: How IT Shapes Competition, Kluwer Academic Publishers, Boston: MA, USA. 91-106.

Necula, G. (1997). Proof Carrying Code, *Proceedings of the 24th Annual Symposium on Principles of Programming Languages.*

Papastavrou, S., Samaras, G., and Pitoura, E. (2000). Mobile Agents for World Wide Web Distributed Database Access, *IEEE Transactions on Knowledge and Data Engineering*, 12(5). Sept. / Oct., 802-820.

Poon C S, Ng L.H (1999) The use of modern building technologies for waste minimization in Hong Kong. *Proceeding of International Conference on Urban Pollution Control Technology* (eds. C.S. Poon, X.Z. Li,). Hong Kong Polytechnic University. Hong Kong. 413-419.

Robert, C. E., and Toby, J. V. (2001). *eBusiness – a beginner's guide*, McGraw-Hill.

Rasdorf, W. J., and Herbert, M. J. (1990). Automated Identification Systems- Focus on Bar Coding. *Journal of Computing in Civil Engineering*. 4(3), 279-296.

Skibniewski, M. J., and Wooldridge, S. C. (1992). Robotic Materials Handling for Automated Building Construction Technology. *Automation in Construction*. 1(3), 251-266.

Stanley-Miller Construction Company (2001). Case Studies: ToolWatch® Shines Light on Thieves: *Stolen Equipment Recovered for Ohio Construction Company*. Retrieved on 22 July 2003 from http://www.toolwatch.com/toolwatch/casestudies/Stanley.php

Stukhart, G. (1995) *Construction Materials Management*. Marcel Dekker, Inc., New York.

Stukhart, G., and Nomani, A. (1992). *Barcode System Standardization*. Source Document 70. Construction Industry Institute.

Stukhart, G., and Cook, E. L. (1990). Barcode Standardization in Industrial Construction. *Journal of Construction Engineering and Management*, ASCE. 116(3), 416-431.

Stukhart, G., and Cook, E. L. (1989). *Barcode System Standardization in Industrial Construction*. Source Document 47. Construction Industry Institute.

Stukhart, G. and Pearce, S. L. (1989). Construction Barcode Standards. *Cost Engineering*. 31(6),19-26.

Stukhart, G. and Pearce, S. L. (1988). Construction Barcode Standards. *Proceedings of 5th International Symposium in Robotics in Construction*. Japanese Society of Civil Engineers. 361-370.

SunMax Corp. (2001). Barcode Basics. Available at http://www.barcodesystems.com

Swartz, J. (1999). The Growing "MAGIC" of Automatic Identification: From Barcodes to Biometrics, and beyond, the future holds exciting challenges and opportunities for the field of Auto ID. *Robotics and Automation Magazine*. 6(1). (ISSN 1070-9932)

Sandholm, T., and Huai, Q. (2000). Nomad: Mobile Agent System for an Internet-Based Auction House, *IEEE Internet Computing*, 5(2) 2000. 80-86.

Schuette S D and Liska R W (1994) *Building construction estimating*. McGraw-Hill, Inc. New York. 1994.

Segev, A., Wan, D., and Beam, C. (1995). Designing electronic product catalogs for business value, Results of the CommerceNet Pilot, Berkeley: University of California, Fisher Center for Information Technology & Management, Haas School of Business. http://haas.berkeley.edu/~citm/cat-proj.html.

Sirinivasan, K., Kekre, S., and Mukhopadhyay, T. (1994). *Impact of Electronic Data Interchange Technology on JIT Shipmenets*, Management Science, 40, 10, 1291-1304.

Stanoevska-Slabeva, K., Schmid, B. (2000). Internet electronic product catalogs: an approach beyond simple keywords and multimedia, *Computer Networks*, Vol. 32, 701-715.

Strader, T., and Shaw, M. (1997). *Characteristics of Electronic Markets*, Decision Support Systems, 21, 185-198.

Stukhart, G (1995) *Construction materials management*. Marcel Dekker, Inc., New York. 1995.

Timm, U., Rosewitz, M. (1998). Electronic sales assistance for product configuration. *Proceedings of the 11th International Bled Electronic Commerce Conference – Electronic Commerce in the Information Society*, Bled, Slovenia, vol. 1, 8-10.

Tang, H. (2001). Construction for Excellence: Thesis of the Construction Industry Review Committee. Central Government Offices, Hong Kong Special Administrative Region, China.

Thomas, G., and Bone, R. (2000). Innovation at the cutting edge: The experience of three major infrastructure projects. CIRIA Publication C548. London, UK.

Trimble (2002) *Mapping & GIS*. <http://www.trimble.com/mgis.shtml>
MFE (2004) (Ministry for the Environment, New Zealand), Construction and demolition waste. <http://www.mfe.govt.nz/issues/waste/construction-demo/>.

Wang, E., and Sedimann, A. (1995). *Electronic Data Interchange: Competitive Externalities and strategic Implementation Policies*. Management Science, 41(3), 401-418.

Whinston, A. B., Stahl, D. O., and Choi, S. (1997). *The Economics of Electronic Commerce.* Indianapolis, IN: Macmillan Technical.

Wirt, D., Showalter, W. E., and Crouch, G. (1999). Integrating Permanent Equipment Tracking with Electronic Operations and Maintenance Manuals. *Durability of Building Materials and Components 8 (Volume Four): Information Technology in Construction*. (Edited by Lacasse, M. A., and Vanier, D. J.) (CIB W78 Workshop) NRC Research Press. 2716-2723.

Wong, TC, Mak, H and Li H (2002) Computer Aided Construction Management, a new paradigm. In Anson M, Ko, J M and Lam, E (eds) *Advances in Building Technology, Elsevier*, pp. 1569-1576.

Wong, TC and Li H (2000) Intelligent Web-Based Project Management System For Large Scale Construction Projects. Beijing, *Proceedings of Construction Management of Large-scale Projects. 13-16 December, 2000.*

Yang, X., Liang, X. J., Zhang, X. Y. (2000). *Geographic Information and Transportation System in E-commerce*. China Telecommunications Construction, 12, 3, 58-64.

Websites:

- http://www.asimaterials.com
- http://www.asia-steel.com
- http://www.assetline.com
- http://www.bciasia.com
- http://www.buildgate2000.com
- http://www.building.com.hk
- http://www.conmex.com
- http://www.chinabidding.com.cn
- http://www.dell.com
- http://www.econstruct.org
- http://www.esd.gov.hk
- http://www.ets.com.hk
- http://www.gis.com

http://www.iai-na.org

http://www.macrobuild.com

http://www.skylinehongkong.com

http://www.superconstruction.net

http://www.vhcome.com

Zack, M. H. (1999). Managing codified knowledge. *Sloan Management Review*, 40(4), 45-58.

ZweigWhite (2002). 2002 Information Technology & E-Business Survey of A/E/P & Environmental Consulting Firms. ZweigWhite. Retrieved in July 2003 at zweigwhite.com

Appendix 1: Questionnaire for VHBuild™ Evaluation

This appendix presents results identified from a survey study which has been conducted upon users of the VHBuild™ system. This survey collected opinions from the users in the form of questionnaire survey. The users included 3 Senior Architects, 5 Project Architects, 6 Project Structural Engineers, 8 Clerk of Works, 12 Site Agents and the Deputy Site Agents.

Participant information:

Name: ________________________ Position: __________________________
Organization: ____
Date of starts using VHBuild: ____________________________________

Section 1: Culture and user acceptance

1.1 Culture

1.1.1 How efficient do you think the Hong Kong construction project management work is?
❑Very efficient ❑Efficient ❑Inefficient ❑Very inefficient

1.1.2 To what level do you think Hong Kong construction industry is utilizing IT in project management?
❑Intensive ❑Fair ❑Rare ❑Very Rare

1.1.3 How efficient do you think is the information flow in a construction project?
❑Very efficient ❑Efficient ❑Inefficient ❑Very inefficient

1.1.4 Which of the following benefit(s) do you think IT tools can provide in a construction project?
❑Bring all project participants to work together more efficiently and effectively.
❑Improve information flow along the construction value chain.
❑Automate repetitive task.
❑Easy retrieving of information.
❑Others:
____

1.1.5 Which of the following do you think is/are the barrier(s) to implement IT application in managing construction project?

❑Fragmented nature of the project team which make adoption of common IT tools across disciplines difficult.
❑Lack of centralized data system and common IT platform.
❑Lack of practical application solution in the market that suit Hong Kong construction market.
❑Lack of IT application with Chinese interface.
❑Low awareness of IT benefits in management level.
❑Low level of IT knowledge among construction practitioners.
❑Work flow change is not inline with IT tools implementation

❑Others: ____

1.1.6 Which of the following solution(s) that you think can help overcoming barrier to implement construction project management IT application ?

❑Strong local customer services, support and training.
❑Customized application and service.
❑Supporting staff with adequate local construction knowledge.
❑Provide IT application that does not require too many changes to the existing workflow.
❑Provide IT application that does not require too much learning.
❑Provide IT application with Chinese interface.
❑Standardization of IT tools, platform and digital formats.
❑Others: ____

1.2 Learning curve and user acceptance

1.2.1 Which of the following application(s) are you familiar with?

❑Microsoft Windows
❑Office tools (e.g. word processing, spreadsheet, etc.)
❑Internet tools (e.g. browser, e-mail)
❑Scheduling tools (e.g. MS project)
❑CAD tools

1.2.2 How much time did you take to make yourself familiar with the operations of VHBuild™?

❑ 1 week ❑ 2 weeks ❑ 3 weeks ❑ 4 weeks ❑ Others:_________

1.2.3 Which of the following facility(s) could help you to use VHBuild™ to perform project management tasks more smoothly?

❑Dedicated technical and clerical support staff.
❑High bandwidth Internet connection.
❑Desktop PC with higher performance.
❑Document Scanner.
❑Digital camera.
❑Others: ____

Section 2: Problems in existing practice

This section aims to identify issues in the existing practice that could be improved by implementing project hosting system (PHS).

2.1 Project Communication and Collaboration

2.1.1 If a document is circulated to 5 people. 2 persons make comments on it, and circulate back to all 5 people. The team leader then collects all comments and makes a decision/conclusion. What is the average turnaround time would you guess?

❑Within 1 day ❑2 to 5 days ❑ 1 week ❑2 weeks ❑Others:_________

2.1.2 In the above case, How would you track the comments made by each? ____

2.1.3 Under a construction design coordination situation, How much time in average would you take to complete the discussion in a design conflict?

❑Within 1 day ❑2 to 5 days ❑1 week ❑2 weeks ❑Others:_________

2.1.4 What is the average turnaround time to process a Site Query? (Receiving the query from contractor + Answer the query + Send the answered query back to contractor)

❑Within 1 day ❑2 to 5 days ❑1 week ❑2 weeks ❑Others:_________

2.1.5 How would you track the status of Site Queries?

____

2.1.6 How would you remind yourself in processing unanswered queries before deadline?

____

2.1.7 How much time in average would you take to issue an updated revision of working drawing?

❑Within 5 days ❑5 to 10 days ❑2 weeks ❑3 weeks ❑Others:_________

2.1.8 Do you agree that the communication channel between you and other parties in the construction project needs improvement?

❑Very agree ❑Agree ❑Disagree ❑Very disagree

2.2 Site Monitoring & Quality Control

2.2.1 How much time does it take to receive the latest copy of site photos, from the time the photo is taken to the time it is delivered to your desk?

❑Within 1 day ❑1 to 2 days ❑3 to 5 days ❑1 week ❑Others:_________

2.2.2 What would you do if you want to inspect and approve the finishing interface/any special events of a particular site location?

____

2.2.3 How much time does it take to receive the latest Daily Reports from site?

❑Within 1 day ❑1 to 2 days ❑3 to 5 days ❑1 week ❑Others:_________

2.2.4 Do you think the existing control mechanism for the following monitoring tasks are enough?

	Enough 4	→ 3	Not enough 2	1
Monitoring of construction work progress	❑	❑	❑	❑
Monitoring of safety works	❑	❑	❑	❑
Monitoring of Quality	❑	❑	❑	❑

2.3 Project information management

2.3.1 If you want to locate a letter from the site agent regarding the subject: 'Tile Setting Out in Precast Bathroom' received about 15 months ago. What would be the normal processes you have to take to accomplish this? Please estimate how much time it take to accomplish this.

❑Within 1 day ❑1 to 2 days ❑3 to 5 days ❑1 week ❑Others:_________

2.3.2 If you want to get the part plan of the bathroom of a working drawing with a particular drawing number. What would be the normal processes you have to take to accomplish this? Please estimate how much time it takes to accomplish this.
❑Within 1 day ❑1 to 2 days ❑3 to 5 days ❑1 week ❑Others:_________

2.3.3 How efficient do you think are the following tasks?

	Very efficient →			Very inefficient
	4	3	2	1
Circulation of project information	❑	❑	❑	❑
Tracking of information delivery	❑	❑	❑	❑
Retrieving of information	❑	❑	❑	❑
Searching of information	❑	❑	❑	❑

2.3.4 About how much time in average does it take to receive the following project document, from the date it is completed?

	Time
Site meeting records	_____________
Contractor/ COW/ BSI reports	_____________
Safety audit reports/Typhoon accident reports/Test result	_____________
Site direction	_____________
Site progress photos/Inspection records	_____________
Project programme	_____________
Daily reports	_____________

2.3.5 If you aware that there is some information missing in a sample submission document. How much time in average would it take to get the right information back?
❑Within 1 day ❑1 to 2 days ❑3 to 5 days ❑1 week ❑Others:_________

Section 3: Benefits offered by project hosting system (PHS)

This section aims to find out the benefits that project hosting system (PHS) can offer base on your experience on using VHBuild^{TM} .

3.1 Project communication and collaboration

3.1.1 If a document is circulated to 5 people. 2 make comments on it, and circulate back to all 5 people. The team leader then collects all comments and makes a decision/conclusion. What is the average turnaround time would you guess with the use of VHBuild^{TM} ?
❑Within 5 hours ❑1 day ❑2 to 3 days ❑4 to 7 days ❑Others:_________

3.1.2 In the above case, How much time in average would you take to complete the discussion in the design conflict with the use of VHBuild^{TM} ?
❑Within 5 hours ❑1 day ❑2 to 3 days ❑4 to 7 days ❑Others:_________

3.1.3 What is the average turnaround time of processing a Site Query with the use of VHBuild^{TM} ? (Receiving the query from contractor + Answer the query + Send the answered query back to contractor)
❑Within 5 hours ❑1 day ❑2 to 3 days ❑4 to 7 days ❑Others:_________

3.1.4 Which of the following PHS function(s) can help you to improve the efficiency of communicating Site Query?

❑Online circulation of Site Query.
❑Online circulation of Site Query answer.
❑Online tracking Site Query status.
❑Others:____

3.1.5 Which of the following PHS function(s) can help you to improve the efficiency of drawing design communication?
❑Access of drawing files online.
❑Online access and editing of remark on a drawing.
❑Online circulation of drawings and remarks
❑Others:____

3.2 Site Monitoring and Quality Control

3.2.1 Which of the following PHS function(s) can help you to improve the efficiency of inspection and approval of joints/finishings/any special events in a particular site location?
❑Instant upload and access of query sheet of the event.
❑Instant upload and access of voice note of the event.
❑Instant upload and access of picture of the event.
❑Instant upload and access of video of the event.
❑Others:____

3.2.2 Which of the following PHS functions(s) can help you to get a clearer picture of site activities?
❑Online access of updated general project information.
❑Web camera access to site activities.
❑Instant availability of latest site progress photos.
❑Instant availability of site daily report.
❑Others:____

3.3 Project information management

3.3.1 How much time would you expect to search the following document with the use of VHBuild™ ?

	Time
Site meeting records	____________
Contractor/ COW/ BSI reports	____________
Safety audit reports/Typhoon accident reports/Test result	____________
Site direction	____________
Site progress photos/Inspection records	____________
Project programme	____________
Daily reports	____________

3.3.2 How much time would you expect in average to receive the following project document with the use of VHBuild™ , from the date it is completed?

	Time
Site meeting records	____________

Contractor/ COW/ BSI reports	______
Safety audit reports/Typhoon accident reports/Test result	______
Site direction	______
Site progress photos/Inspection records	______
Project programme	______
Daily reports	______

3.4 Paper saving

3.4.1 How many sets of the same paper document should be produced for the various types of project document with the use of VHBuild™ ?

Items:	Number of Copies
Safety Plans	______
Safety reports	______
Sample submissions	______
Query sheets	______
Site memos	______
Site directions	______
A.I./ S.I.	______
Master programmes	______
Progress reports	______
Test results	______
Shop drawings	______
Working drawings	______
Standard drawings	______

3.5 Comment specific to VHBuild™

3.5.1 Please give a score to the following functions in VHBuild™ according to their ability to improve your working efficiency. (higher is better)

	4	3	2	1
General project information summary	❑	❑	❑	❑
Site photos	❑	❑	❑	❑
Site daily report	❑	❑	❑	❑
Site meeting records	❑	❑	❑	❑
Contractor/ COW/ BSI reports	❑	❑	❑	❑
Test results	❑	❑	❑	❑
Inspection records	❑	❑	❑	❑
Project programmes	❑	❑	❑	❑
Project drawings	❑	❑	❑	❑
Internal circulation	❑	❑	❑	❑
Web camera	❑	❑	❑	❑

3.5.2 Do you agree that "Search Drawing" is a useful function in a project hosting system?

Very agree → Very disagree

4	3	2	1
❑	❑	❑	❑

3.5.3 Do you agree that "Compare Drawing" is a useful function in a project hosting system?

Very agree → Very disagree

4	3	2	1

❑ ❑ ❑ ❑

Section 4: General comment

4.1 How important do you think the following criteria is in selecting project hosting system?

	Very important 4	→ 3	2	Very unimportant 1
Fit to local practice	❑	❑	❑	❑
Packages' features fit user needs	❑	❑	❑	❑
Immediately available	❑	❑	❑	❑
Level of customization	❑	❑	❑	❑
Local Customer Service and Support	❑	❑	❑	❑
Provide adequate training	❑	❑	❑	❑
System and data security	❑	❑	❑	❑
User friendliness	❑	❑	❑	❑
Reliability and stability	❑	❑	❑	❑
Level of changes to existing workflow	❑	❑	❑	❑
Chinese interface	❑	❑	❑	❑

4.2 To what extent do you agree that project hosting system can provide the following benefits?

	Very agree 4	→ 3	Very disagree 2	1
Better quality of decisions	❑	❑	❑	❑
Faster response time	❑	❑	❑	❑
Cost saving	❑	❑	❑	❑
Time saving	❑	❑	❑	❑
Prevent error	❑	❑	❑	❑
Streamline the existing information flow	❑	❑	❑	❑

This is the end. Thank you very much for your time and effort.