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Mobile Construction Supply Chain Management Using PDA and Bar Codes

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Abstract: *Construction project control aims to effectively obtain real-time information and enhance dynamic control by utilizing information sharing and connecting involved participants of the projects to reduce construction conflicts and project delays. However, extending the construction project control system to job sites is not considered efficient because using notebooks in a harsh environment like a construction site is not particularly a conventional practice. Meanwhile, paper-based documents of the site processes are ineffective and cannot get the quick response from the office and project control center. Integrating promising information technologies such as personal digital assistants (PDA), bar code scanning, and data entry mechanisms, can be extremely useful in improving the effectiveness and convenience of information flow in construction supply chain control systems. Bar code scanning is appropriate for several construction applications, providing cost savings through increased speed and accuracy of data entry. This article demonstrates the effectiveness of a bar-code-enabled PDA application, called the mobile construction supply chain management (M-ConSCM) System, that responds efficiently and enhances the information flow between offices and sites in a construction supply chain environment. The advantage of the M-ConSCM system lies not only in improving the efficiency of work for on-site engineers, but also providing the Kanban-like visual control system for project participants to control the whole project. Moreover, this article presents a generic system architecture and its implementation.*

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1 INTRODUCTION

The construction industry is one of the most complex industries because the total development of a project normally consists of several phases requiring a diverse range of specialized services and involvement of numerous participants. Therefore, it is not easy to control and manage construction projects effectively. A real-time monitor and control system for construction projects may be necessary and helpful in completing the projects and to meet budget and deadline. With the advent of the Internet, web-based information management solutions allow information dissemination and sharing among all the project participants. Usually, construction managers and on-site engineers need access to the construction site to manage the project because most of the construction projects are operated in construction sites. Nowadays, desktops and notebooks have become essential tools in construction management. However, the current desktops and notebooks are not suitable for the construction sites because of inconvenience in carrying. On-site engineers generally handle various types of digital information, such as drawings, specifications, checklists, and daily reports. They usually use sheets of paper and/or field notes. As a result, there is a gap in time and space between the construction site and the office, which leads to low efficiency and lack and confusion of data.

Information technology (IT) plays an important role to control and manage construction projects successfully, especially in enhancing communication and coordination among participants. Communication and coordination need to be maintained to support the sharing of resources and competencies in the network of a construction chain. Furthermore, integrating promising information technologies such as personal digital assistants (PDA), bar code scanning, and data entry mechanisms, can be extremely useful for improving the effectiveness and convenience of information flow in construction supply chain systems. This article presents a novel system called the mobile-based construction supply chain management (M-ConSCM) system to improve construction information acquisition on site and provide an information-sharing platform among all participants of the construction chain utilizing web technology and bar-code-enabled PDA.

1.1 Problem statements

The performance of project management and control can be improved by enabling each participant to share information with others. However, two important aspects of information sharing are information acquisition and information communication. Information acquisition problems in a construction project follow from the fact that most of the data and information are gathered from the construction site, which is an extension of the construction chain. The effectiveness of information and data acquisition influences the flow of information between the office and the construction site. However, on-site engineers usually use written documents, drawings, contracts, specifications, and shop drawings for job sites. As a result, a gap in time and space between the job site and office causes the duplex, lack and confusion of data and information. In other words, existing means of processing information and collecting data are not only time consuming and costly, but also reduce the performance of project management in information acquisition. Furthermore, construction contractors normally depend on interactions over the telephone or fax machine to communicate with suppliers, subcontractors, and designers. Consequently, transactions are often lost or misunderstood. Such means of communicating information between sites and offices, and among all participants, are ineffective and inconvenient.

1.2 Research objectives

A web portal is developed to solve the information communication problem. This portal is controlled by a general contractor and provides subcontractors and suppliers with real-time project-related information-sharing services, dynamically responding to the entire construction supply chain network. In this article, a mobile construction supply chain management (M-ConSCM) system is developed to be efficient and cost effective, to improve practical communication among participants, and to increase flexibility in terms of project delivery and response times. The M-ConSCM system is a web-based system utilized to effectively integrate general contractors, subcontractors, and suppliers, such that construction merchandise is made and distributed in the right quantities, to the right locations, at the right times.

Paper-based documents are being superseded by integrating PDAs and bar code systems with the M-ConSCM system to solve the information acquisition problem. PDAs can extend M-ConSCM systems to construction sites. The efficiency of data collection can also be improved using automated bar-code-enabled PDAs to enter and edit data on the job site. By using web technology and mobile devices, the M-ConSCM system for general contractors creates tremendous potential to increase the efficiency and effectiveness of information flow, thereby streamlining construction processes with other participants.

The on-site engineer often wastes time by traveling to obtain information when no other efficient means of communication is available. The portal and PDAs allow on-site engineers to update data from the construction site and then upload them immediately to the supply chain web portal; suppliers and subcontractors can receive real-time project-related information and make better decisions for the future management and control of the project. The system enables project managers to make the right decision in a "quick-response" environment.

This research develops a mobile supply chain control system for construction projects. The constituent objectives include (1) developing a framework for a mobile supply chain control system for construction contractors; (2) applying such a system that integrates bar codes with PDA technology to increase the efficiency of job site data collection; (3) developing a web-based portal for construction supply chain control providing real-time information and wireless communication between offices and sites, subcontractors, and suppliers; (4) providing on-site engineers with updated information, accessed via the internal supply chain control system between the office and the job site; and (5) supporting project managers

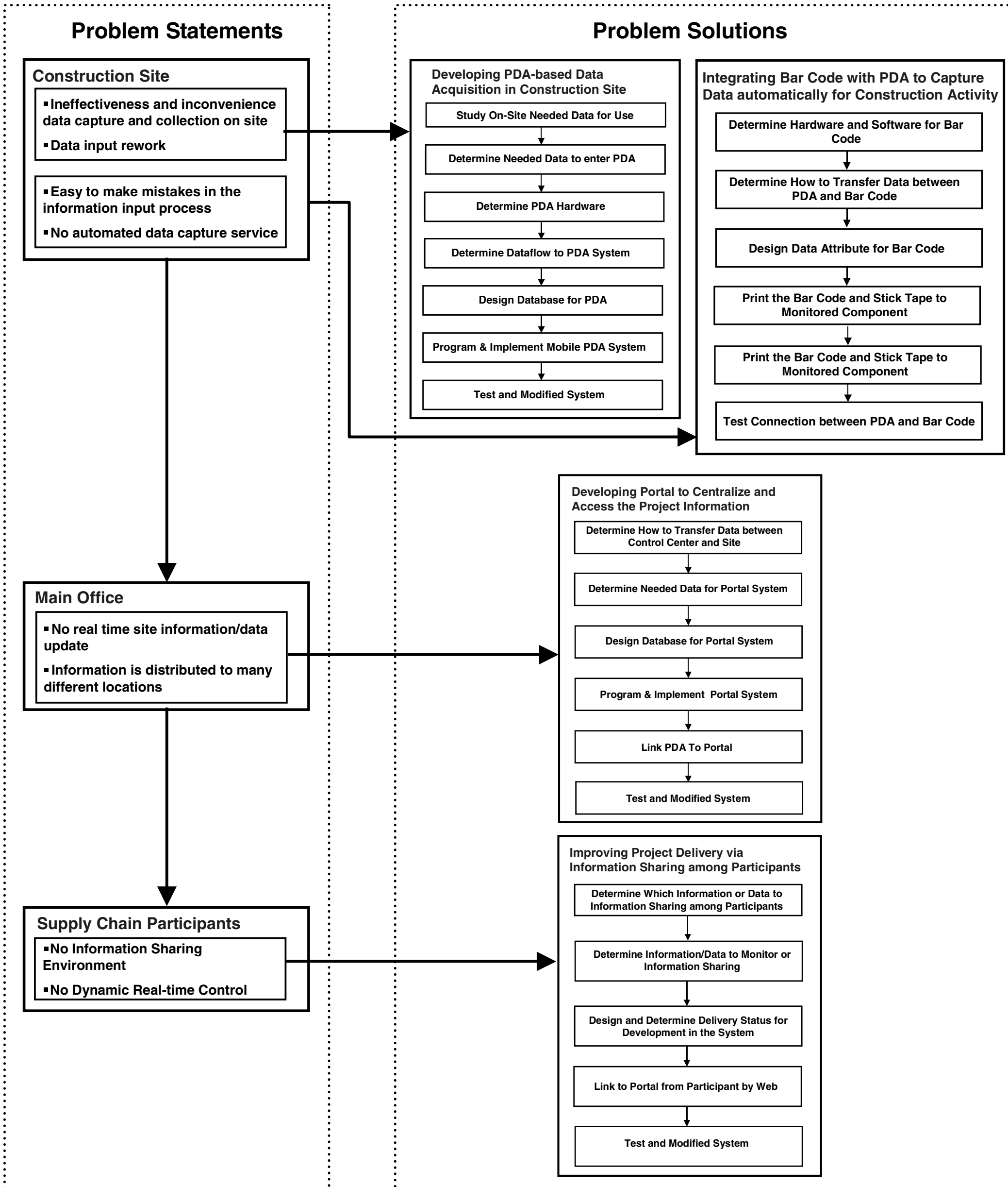

Fig. 1. Problem statement and problem solutions for construction information acquisition on site and information sharing among participants.

of each partner to monitor and control the construction process dynamically. Figure 1 illustrates solutions used in the real case of a construction in Nankang Software Park in Taipei, by Century Development Corporation. With appropriate modifications, the M-ConSCM system can be utilized at any construction site for contractors or suppliers in support of the M-ConSCM system.

2 CONSTRUCTION SUPPLY CHAIN FRAMEWORK FOR GENERAL CONTRACTORS

Supply chain management (SCM) is a concept that originated and flourished in the manufacturing industry. The first visible signs of SCM were in the Just-In-Time (JIT) delivery system, as part of the Toyota Production System (Shingo, 1988; Ruben and Lauri, 2000). The supply chain has been defined as "the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer" (Christopher, 1998). SCM is the supply chain management of activity from raw material supply to consumer to minimize the time taken to perform each activity, eliminate waste, and offer an optimal response by maximizing value (Robert and Nichols, 1999). Tserng and Lin (2002) combine the

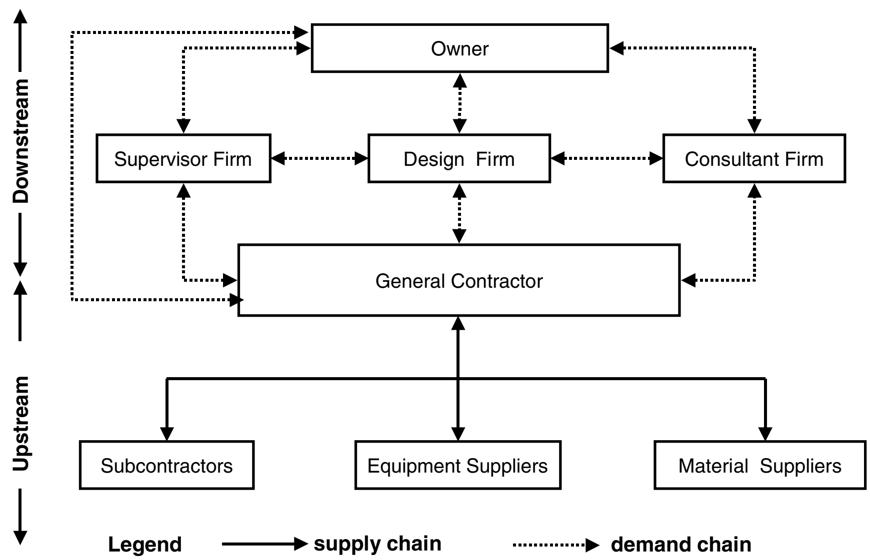

Fig. 2. Construction supply chain framework for the general contractor.

quick response mechanism of IT with portfolio theory in financial management to develop the Accelerated Subcontracting and Procuring (ASAP) model for construction supply chain management. An organization does more than merely managing its own portion of the supply chain. The process usually involves suppliers and users, as well as ancillary organizations.

Supply chain control (SCC) is one of the important parts of SCM. Supply chain control in construction usually involves a group of companies and individuals working collaboratively in a supply network of interrelated processes or activities designed most effectively to satisfy end-customer needs, while rewarding all members of the chain (Arbulu and Tommelein, 2000). Supply chain control in construction is recognized as improving the process of information flow, saving costs, and supporting revenue-enhancing business strategy.

Figure 2 presents an overview of the construction supply chain framework for the general contractor. The upstream supply chain for the general contractor includes superintendents, architects/designers, consultants, and the owner. The downstream supply chain includes subcontractors, equipment suppliers, and material suppliers.

Usually, the construction supply chain includes an internal supply chain and an external supply chain (see Figure 3). From the general contractor's perspective, the internal construction supply chain is the internal network among the head office, job-site office, and job site. Besides, the external construction supply chain is a big and complicated organization. With the assistance of Internet technology and applications, the internal network and external network can be chained together to improve construction project information and communication (Lin and Tserng, 2003a).

In the construction projects, most initial construction data come from the construction site. On-site engineers obtain data on the job site and bring it back to the office so that project managers can make the right decisions using his/her tools. Accordingly, the effective acquisition of accurate data from the job site plays an important role in governing the performance of the system.

Information sharing eliminates the need to regenerate or reenter the same information in different offices. Eliminating multiple data entry also helps maintain data consistency and reduces human errors. For instance, the staff in the estimating department estimated the required quantity of cement in a project. With this information together with the project schedule, a purchasing officer can use the information and place an order. Traditionally, this information is reentered into various isolated systems such as scheduling and purchasing systems. With information sharing, the information is entered once and shared with other departments and partners.

The construction industry is one of the most complex industries because its products are unique and several participants are usually involved in the project. Participants change in every construction project. Consequently, developing a formalized SCM system for the construction industry is extremely difficult. However, IT critically enables effective supply chain control (Simchi-Levi et al., 2000), as is demonstrated by the ConSCM system, which uses various technologies to share and distribute information.

Designing the framework of a construction SCM system in activity-based units is helpful, because

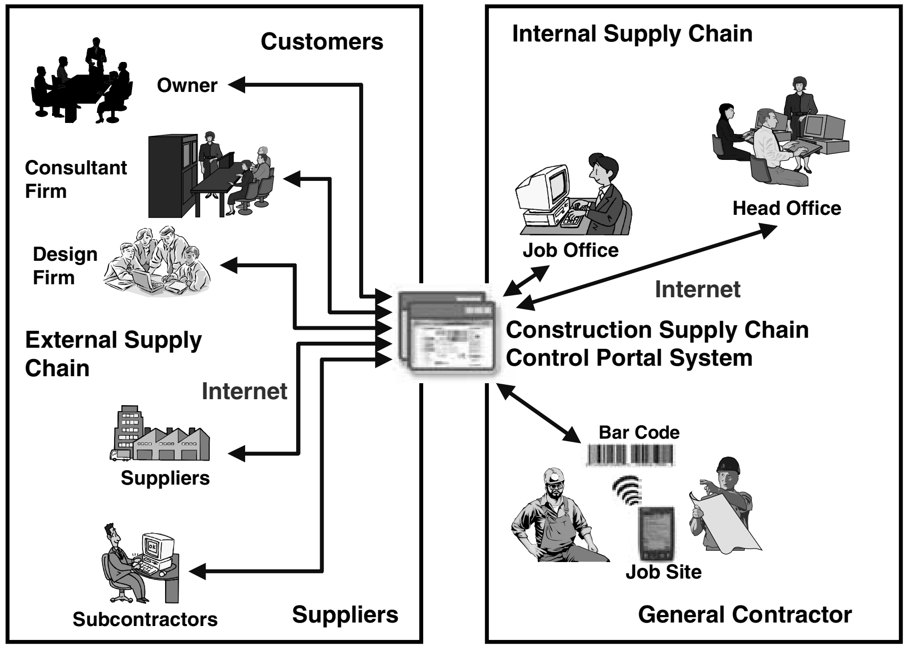

Fig. 3. Framework of internal and external construction supply chain.

construction projects are normally distinguished and analyzed in activity units. Figure 4 presents a sample construction process, in which each activity of the project has manpower, equipment, and material supply components. The upper part in Figure 4 is expressed in the way of traditional schedule controlling for the activity, the lower part is explained with the combination of supply, delivery, and traditional schedule controlling for the component supply and delivery of each activity. The resulting combination allows any project participants to trace and control their project more efficiently and progress while being fully integrated with the supply chain concept. The stockpile following steel assembly means waiting status before steel assembling finishes and the stockpile for concrete placement means waiting status before concrete placement starts. The information sharing is the key to the success of a supply chain because it enables project participants to make decisions that cross both systems and companies (Sunil and Peter, 2001). A practical construction SCM system can incorporate PDA, bar code, and portal technologies to empower participants in construction projects. The rest of this section discusses the use of PDAs, bar code systems, and portals in more detail.

2.1 Using PDAs on construction sites

Various kinds of mobile device have been adapted to field jobs on construction sites. Recently, the PDA revolution has come to the construction industry. The popularity of PDAs is growing rapidly because more powerful devices are being developed and a wider range of applications are becoming available. The main features of PDAs include: (1) access to calendar, address book, notes and to-do lists; (2) browsing the Internet or providing web-clippings; (3) Internet access either via modem, cell phone, or wireless access; (4) synchronizing data between PDAs and desktop PCs; and (5) a platform for add-on software (McPherson, 2000; Johnson and Broida, 2000).

The benefits of using mobile devices in the construction industries have been well documented (Baldwin et al., 1994; Fayek et al., 1998; McCulloch, 1997). Furthermore, mobile devices have been applied in many areas in the construction industries, such as the following: (1) to provide wearable systems to support field inspection (Sunkpho and Garrett, 2003); (2) to support pen-based computer data acquisition for construction survey records (Elzarka and Bell, 1997); (3) to support collaborative and information-sharing platforms (Pena-Mora and Dwivedi, 2002), and (4) to utilize mobile computers to access data capture for piling works (Ward et al., 2003).

In a construction project, engineers and workers need to be provided with the latest available information on the construction site. To understand the problems on construction sites and solving them with PDAs, a survey was conducted during a construction project of Nankang Software Park located in Taipei by Century Development Corporation, to determine the information required by on-site engineers. Project managers, on-site

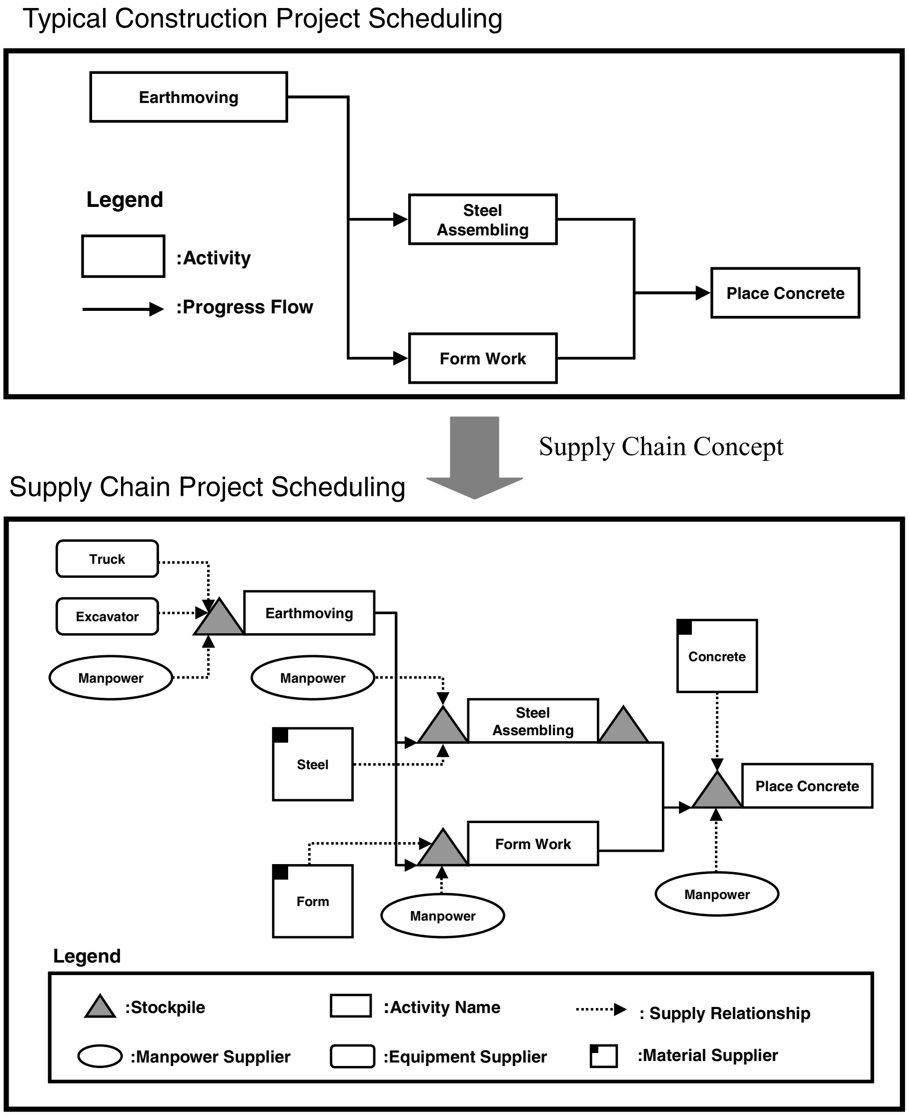

Fig. 4. Construction supply delivery supporting illustration of an example.

engineers, and general engineers completed the survey: the response rate to the 20 questionnaires was 90% (18 responses). The survey was made to identify the domain knowledge that relates to the problems on the construction site and to classify information required at the construction site. The result of the survey is summarized in Table 1 and Figure 5. Table 1 shows how PDAs can provide support in situations that commonly arise on construction sites. Figure 5 shows the applications of PDAs on construction sites.

2.2 Applying bar code to construction

Bar code is an automatic identification solution that streamlines identification and data acquisition. Furthermore, bar code has been applied to many fields since the early 1960s, such as assembly checking, fixed asset inventory control, tracking, and records management. In the construction industry, Bell and McCulloch (1988) started a research project to explore the potential applications and the resulting cost-saving benefits of bar code use in construction. Then, the application of bar code has been used in many areas in the construction industry, as follows: (1) to identify and find materials and build components on a construction job site (Bell and McCulloch, 1988; Bernold, 1990; Anderson, 1993; Skibniewski and Wooldrige, 1992; McCulloch and Lueprasert, 1994); (2) to automate yard control to reduce loss and misidentification of material and equipment (Lundberg and Beliveau, 1989); (3) to track and manage both small and

Table 1
Problems on construction sites and their solutions with PDAs

Function	*Current status*	*Problem*	*Solution with PDAs*
Control			
Inventory control			Assist on-site engineers handle inventory management on the site
Maintenance control	Paper-based work	Time-consuming and ineffectively distributed	Assist on-site engineers handle asset maintenance management on the site
Schedule control			Assist on-site engineers to handle schedule control on the site
Quality control			Assist on-site engineers to handle quality control on the site
Record			
Experience record			Provide on-site engineers a portal tool to write down know-how tips on the site
Process record (voice)	Inconvenient & not handy	Inconvenient, no handy devices	Provide on-site engineers a portal tool to write down experience tips on the site
Process record (photo)			Easy for on-site engineers to record construction process
Process record (video)			Easy for on-site engineers to record construction process
Communication			
E-mail	N/A	N/A	Provide on-site engineers to send and read e-mail by PDA
Reference			
E-drawing			Help on-site engineers refer to the construction drawings directly from PDA
E-specification	Paper-based work	Dreadful, inconvenient	Help on-site engineers refer to the specification directly from PDA
E-contract			Help on-site engineers refer to the contract directly from PDA
E-manual			Help on-site engineers refer to the manual directly from PDA

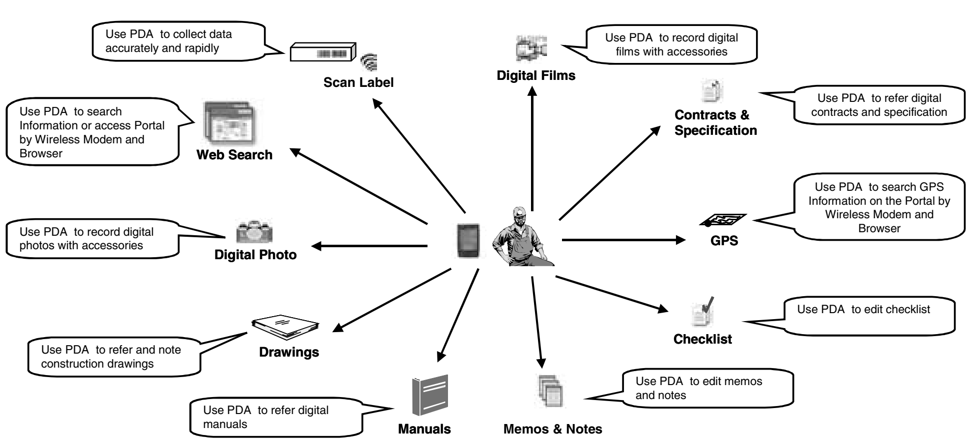

Fig. 5. Application of PDAs used on construction sites.

large equipment on the job site (Wirt et al., 1999); (4) to track job-site workers (Bell and McCulloch, 1988); (5) to support scheduling, resulting in better budgetary control and substantial cost savings (Blakey, 1990); (6) to identify documentation, drawings, material, equipment, and project activities (Stukhart and Cook, 1990; Rasdorf and Herbert, 1989; Finch et al., 1996); and (7) to integrate bar code and GIS for monitoring construction progress (Cheng and Chen, 2002).

Bar code technology can be used with PDAs to enable on-site engineers to integrate seamlessly work processes at job sites because of its accuracy and ability to capture data effectively. With a bar code scanner plugged into a PDA, the bar-code-enabled PDA can be a powerful portable data collection tool. Additionally, bar code readings increase the accuracy and speed of information communication, indirectly enhancing performance and productivity.

2.3 Using a portal in the construction supply chain

Portals, a unique but occasionally complex concept introduced in the late 1990s, are web sites that collect information related to specific themes or topics and provide users with access to related services and information sources. Besides, a portal is an ideal platform for sharing information in a supply chain system. When a portal is used, all project-related information that is centralized in a project database can be obtained only through a web interface. The portal also provides authentication and access control mechanisms so that project participants can access information according to user privileges and activity-related units. In practice, however, the exchange of information among participants is not as easy as it seems. Several different systems and standards are used; the peer-to-peer relationships among companies in the network are normally too many to manage, and most systems do not support easy exchange of information with other systems. Furthermore, most participants are very reluctant to share information with other participants. A portal represents a solution to these problems. Tserng and Lin (2003) develop an electronic acquisition model for project scheduling (e-AMPS) portal to automatically acquire external information and provide participants with construction information sharing. An e-Hub construction supply chain management (Hub-ConSCM) system is developed for information sharing and analysis among project participants (Lin and Tserng, 2003b). Standardized interactions with one portal are easier to manage than are many peer-to-peer relationships. IT can help to solve the problems that plague several supply chains. Electronically exchanging information reduces the number of errors and increases the efficiency of the work processes. When one participant can use the information of other participants in the supply chain, the negative effects of uncertainty can be theoretically eliminated. Figure 6 presents a framework in which all participants share updated information to their related activities via a web portal.

3 DEVELOPMENT OF THE M-ConSCM SYSTEM

The internal construction supply chain management (ConSCM) system can be divided into three subsystems: the construction enterprise resource planning (ConERP) system, the construction supply chain management center (ConSCMCenter) system, and the M-ConSCM system. The M-ConSCM system extends the ConSCM system from offices to job sites to assist with forecasting and analysis services, whereas the ConERP system mainly deals with data transactions in all departments or systems integration within a construction company.

Similar to project scheduling management, M-ConSCM, which is based on the concept of undertaking activities of project planning and control, is developed to integrate M-ConSCM with the ConERP and ConSCMCenter systems. All data are stored and classified by activity-based units in the M-ConSCM system. Also, the M-ConSCM services described in this work are made available to all the participants (suppliers and subcontractors) of a project, through a specially designed portal, which also serves as a real-time and mail communication channel for projects. All the authorized participants can run their quality controls, schedule controls, and inventory-management work, based on the data shared through the portal service. When the data are updated on the server side, e-mails are automatically sent from the server to the general contractor's project manager and participants involved in the relevant activity. The following section presents a detailed treatment of the development of the M-ConSCM system.

3.1 System usage overview

The M-ConSCM system is comprised of three components: PDA, bar code, and portal. Notably, both the PDA and the bar code components are on the client side, whereas the portal component is on the server side (see Figure 7). Within the M-ConSCM system, all project-related information acquired by on-site engineers is centralized in a supply chain system database (portal model database). Project participants (subcontractors and suppliers) in the supply chain may have access to all or some of this information through the portal, depending on their access privileges.

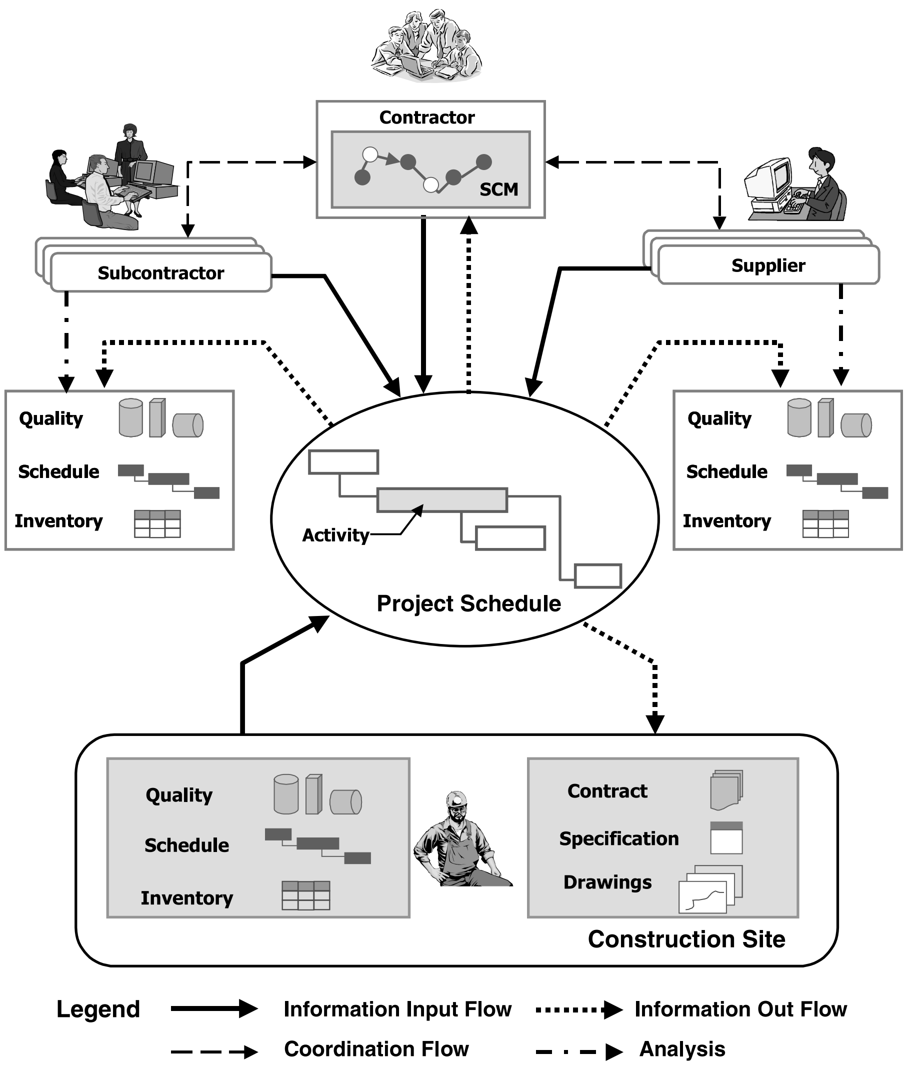

Fig. 6. Information sharing in the project scheduling using the portal.

3.2 System architecture

The server of the M-ConSCM system has three distinct types of layers—presentation, application, and database layers—each with its own responsibilities.

The presentation layer defines administration and end-user interfaces suited to the work of that end user. The users can access information through web browsers, including Microsoft Internet Explorer or Netscape Navigator. Administrators can control and manage information through the web browser as well as a separate server interface.

The application layer defines various applications for information collection and management. These applications offer system security, information sharing, project control, project monitoring, and system administration functions. The database layer includes DB2 Everyplace, DB2 Universal, and SQL Server 2000. All the data are stored and organized in DB2 Everyplace for mobile devices. The data uploaded from mobile devices (client) are stored in DB2 Universal Database as a medium between the server and the client. Finally, SQLServer 2000 processes and manages the M-ConSCM system database.

3.3 Modules of the M-ConSCM system

The M-ConSCM system is composed of a construction supply chain control portal integrated with mobile devices and bar code technology (bar-code-enabled PDA). The following is a brief description for each module.

3.3.1 Web portal module of M-ConSCM system—ConSCM portal. The ConSCM portal is an information hub in the M-ConSCM system for general contractors. The ConSCM portal enables all the participants to log

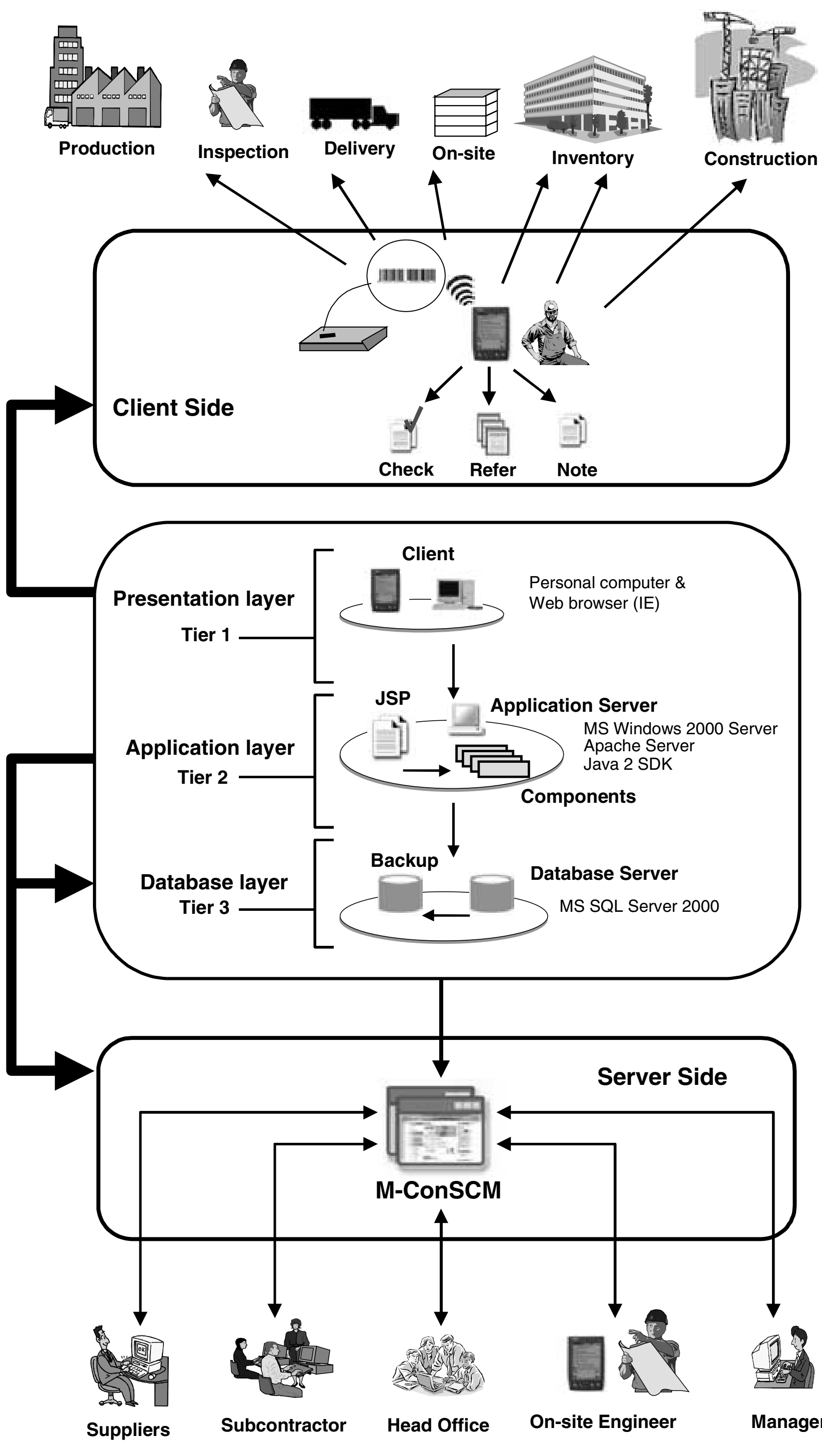

Fig. 7. M-ConSCM system framework overview.

onto a single portal site and immediately obtain the information they need to make their own plan. The portal is a simple presentation such as "Kanban" to both suppliers and subcontractors. It gives suppliers information on the inventory levels of other portal users and allows them to manufacture products accordingly. The GC can access diverse information and services via a single front end on the Internet. For instance, a supplier can log onto the portal, enter an assigned security password, and gain access to real-time information about the production schedule.

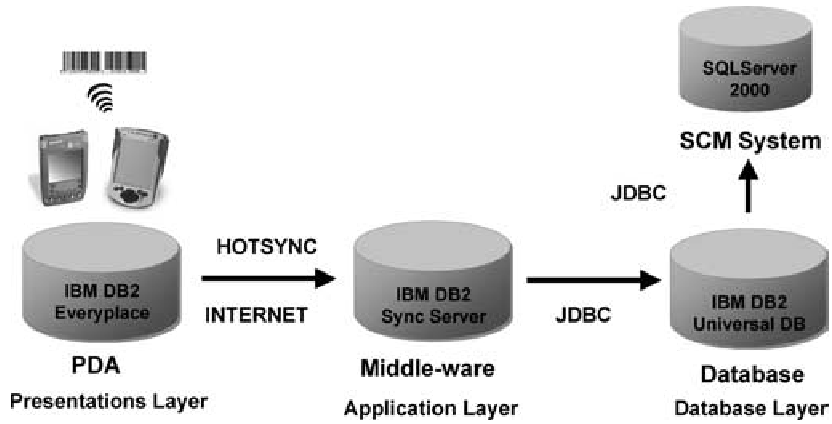

Fig. 8. Information delivery from the PDA.

The general contractor can check on the production or shipping status of an order, the availability of inventory, or a variety of other project-related data.

The ConSCM portal is based on Microsoft's Windows 2000 operating system and Internet Information Server (IIS) as the web server. The prototype is developed using Java Server Pages (JSP), which are easily incorporated with HTML and JavaScript technologies, to transform an Internet browser into a user-friendly interface for users. Microsoft's SQLServer 2000 is used as the database for storing all information. All e-specification and e-contracts saved in the server side must be stored in the e-book format for downloading into PDAs at the job site. The ConSCM portal provides a single personalized gateway that enables all engineers on the ConSCM system to access relevant information sent back from the PDAs. The ConSCM portal provides a solution that involves a single, unified database, linked to all functional systems with different levels of access to information, depending on the user's role, both within an organization and across organizations and other supply chain participants.

3.3.2 Bar code module of M-ConSCM system. Two mobile device platforms, Palm OS and Windows CE, are selected as the bar-code-enabled PDA hardware systems. The M-ConSCM system uses Palm Scanner (Symbol SPT 1500) and iPAQ Scanner (Symbol SPS 3000). In the M-ConSCM system, bar code tags and labels are applied to the materials, equipment, and property, as well as to the item control list. All construction bar code applications in the M-ConSCM system use the Code 39 symbology (Bell and McCulloch, 1988), and bar code labels are printed using high-quality laser printers.

Two types of bar code software are used in this system: bar code labeling software and bar code tracking software. Bar code labeling software provides the function for designing and printing quality labels. Bar code tracking software is applied to read and track the bar codes.

3.3.3 Mobile device (PDA) module of M-ConSCM system. As mentioned in the previous section, Palm OS and Windows CE are the two platforms used to operate the M-ConSCM system. Visual Basic and eMbedded Visual Tools 3.0 are the programming language and tools used to develop the module. IBM DB2 Everyplace and Universal Database serve as the PDA database for the Palm OS-based PDA; SQLServer for CE serves as the PDA database for the Windows CE-based PDA. Additionally, On-site Viewer (http://www.autodesk.com) for Windows CE is installed on the Windows CE-based PDA to allow viewing, marking up, and measuring AutoCAD drawings on the PDA.

In the PDA module, all the data files are first stored in the PDA database before being sent to the server through the Internet. After the application in the PDA is run, all the data files are sent, transformed, and saved in the server side database using open database connectivity (ODBC) and Java database connectivity (JDBC) technologies. Figure 8 shows information delivery from PDA module and Figure 9 offers further detail of the conceptual semantic diagram of the PDA modules. Furthermore, Figure 10 presents an E-R diagram for the PDA module.

3.4 Analysis of the supply delivery process

To trace the supply delivery process, expected variance and actual variance expressed by set (1) and (2) are used, integrated with signal presentation in this system. The expected variance is calculated by the expected available date from supplier-confirmed response for the expected variance. The actual variance is calculated by the actual date from supplier-confirmed response for the

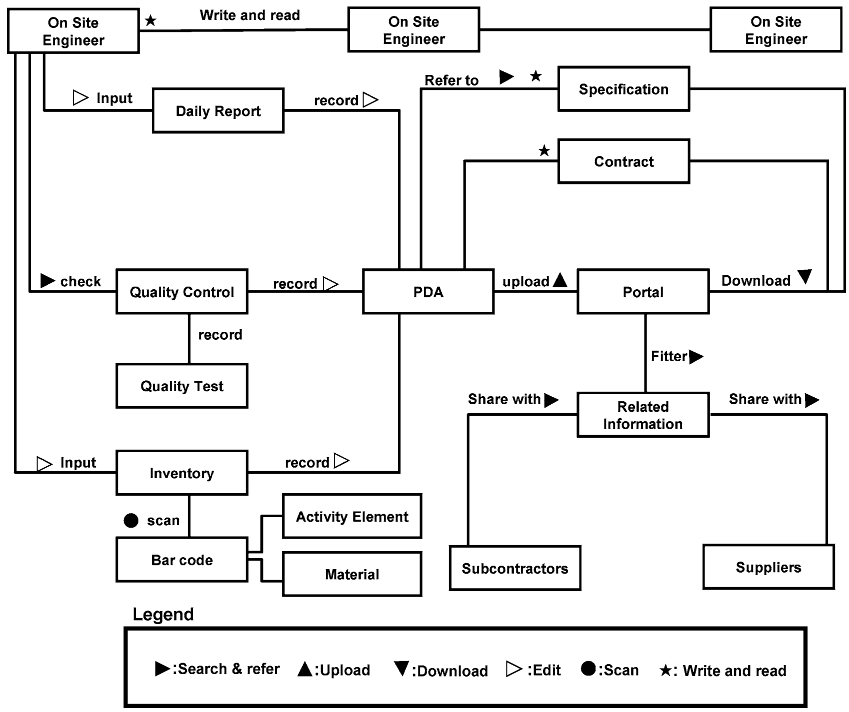

Fig. 9. Conceptual semantic diagram for the PDA module.

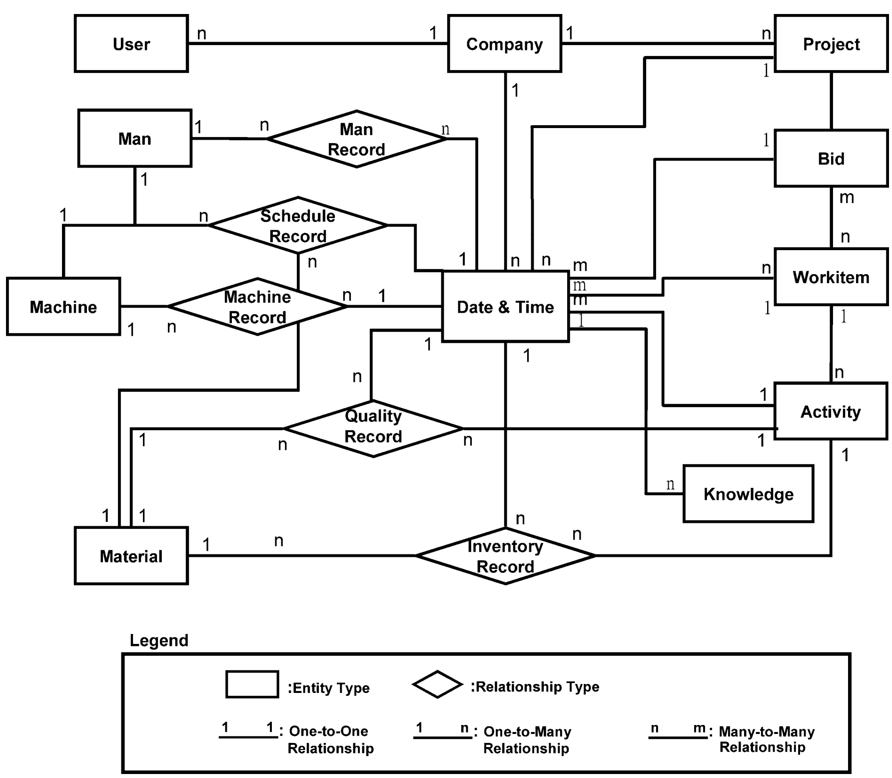

Fig. 10. E-R diagram for the PDA module.

actual variance. Furthermore, a performance index called Supply Performance Index (SPI) is used for measuring the delivery performance. The SPI expressed by set (3) is calculated by dividing actual delivery duration by plan delivery duration. A negative variance and an index of 1.0 or smaller are favorable. If actual delivery duration exceeds plan deliver duration, more attention has been paid for the further project control.

$$\text{Expected variance (EV)} = \text{Expected arrival date} - \text{Plan arrival date} \quad (1)$$

$$\text{Actual variance (AV)} = \text{Actual arrival date} - \text{Plan arrival date} \quad (2)$$

Where Plan arrival date means the arrival or finish date for the delivering component; Expected arrival date indicates actual confirmed delivery data by the supplier; Actual arrival date implies actual delivery date.

$$\text{Supply performance index} = \frac{\text{Actual delivery duration}}{\text{Plan delivery duration}} \quad (3)$$

If expected arrival date is behind plan arrival date, it implies there is not sufficient time to supply or deliver to the job, and the delivery status is possibly behind schedule. If expected arrival date and plan arrival date are the same, the delivery status is possible on schedule. If expected arrival date is ahead of the plan arrival date, the delivery status is possibly ahead of schedule. Similarly, if actual arrival date is behind plan arrival date, it implies the delivery status is late already. If actual arrival date and plan arrival date are the same, the delivery status is on schedule. If actual arrival date is ahead of plan arrival date, the delivery status is ahead of schedule. Table 2 summarizes these statuses and relates them to the variance and signal using in the system.

Table 2
The relationship between variance, status, and signals

Variance	*Status*	*Signal*
$EV > 0$	Delivery status is possibly behind schedule	Light red
$EV = 0$	Delivery status is possibly on schedule	Light yellow
$EV < 0$	Delivery status is possibly ahead of schedule	Light blue
$AV > 0$	Delivery status is already late	Deep red
$AV = 0$	Delivery status is on schedule	Deep yellow
$AV < 0$	Delivery status is ahead of schedule	Deep blue

To illustrate clear progress, there are eight statuses utilized in the system. They are production status, test status, storage status, delivery status, on-site status, inventory status, inspection status, and installation status. These progress statuses may be different from the projects. Engineers just select the proper progress status from the lists in the PDA or portal. When the current status is updated in the portal, the related participants of the activity can understand the newest situation of project progress. Furthermore, the system displays the status of delivery progress in the PDA and portal with different colors. For example, in the delivery process, the graphic feature displayed in deep red represents that the component has been behind schedule. Light red color shows that the component was delivered in the behind-schedule status, and deep blue color signifies that the component is in ahead-of-schedule status. As the installation of the component is completed and confirmed by the on-site engineers, the color of the associated graphic feature is changed to black.

Figure 11 presents an analysis flowchart of the supply delivery status used in the M-ConSCM system. Also, Figures 12 and 13 present the transition of the supply status during the inventory and inspection status.

4 SYSTEM IMPLEMENTATION

This section illustrates the implementation and module of the bar-code-enabled PDAs system.

Daily Report Module: Daily Report module provides on-site engineers with an exhaustive record of daily activities on site. Engineers can record data regarding dates, weather, schedules, work done, situations that have arisen, and manpower, machines, and material in the inventory.

Inventory Management Module: Inventory Management module represents an easy-to-access and portable environment in which on-site engineers can trace and record all information on the status of materials in the warehouse or on the scheduled delivery list. The module enables on-site engineers to better manage inventory on construction sites.

Quality and Inspection Module: On-site engineers may download the most up-to-date tests of quality over the Internet. On-site engineers can enter the test result directly in the PDA. Also, PDA displays the code and/or checklist for each important component and work. On-site engineers can also plot the position of unacceptable on a drawing and select related items from the lists in the PDA. The advantage of the module is that on-site engineers may enter/edit quality and inspection test results on the construction site and all test records can

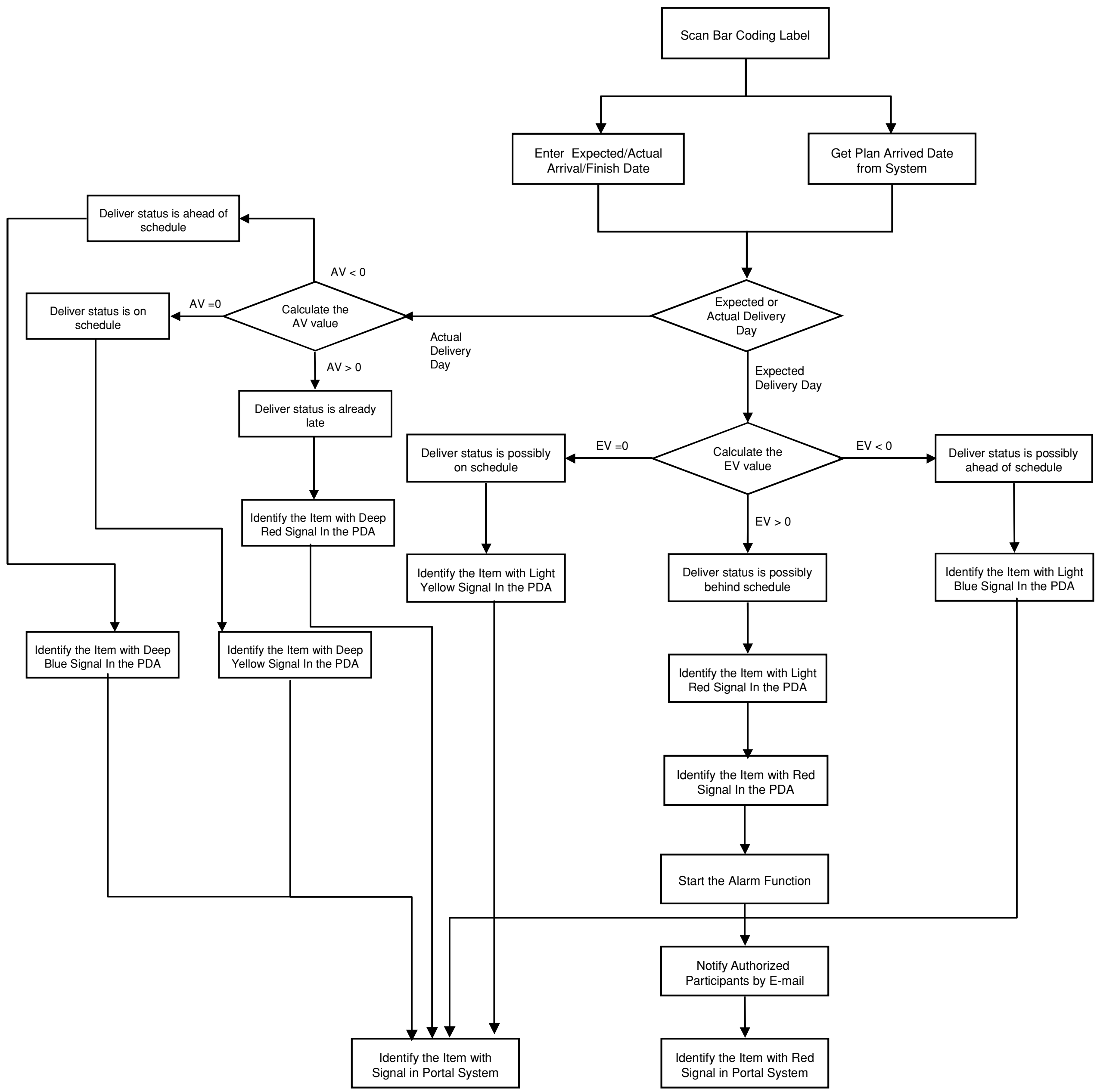

Fig. 11. An analysis flowchart of the supply delivery status used in the M-ConSCM system.

be communicated between the PDA and the portal via real-time synchronization, eliminating the need to enter repeatedly the same data.

Experience Tips Module: Experience Tips module provides on-site engineers with a tool to record their notes, solutions, unsolved problems, and important thoughts on the construction site. On-site engineers enter the information into the PDA and send the information back to the ConSCM portal directly, using the PDA's wireless telecommunication capability. All unsolved problems and valuable experiences will be posted in the ConSCM portal to augment the service of knowledge collection, sharing, and e-learning in the construction field.

Progress Monitor Module: This module has been built for managers and on-site engineers to monitor the progress of the important components. Furthermore, managers, on-site engineers, and project-related participants can share the current progress or delivery condition of these critical works and components. Schedule Management module represents an easy-to-access and portable environment in which on-site engineers can trace and record all information on the status of

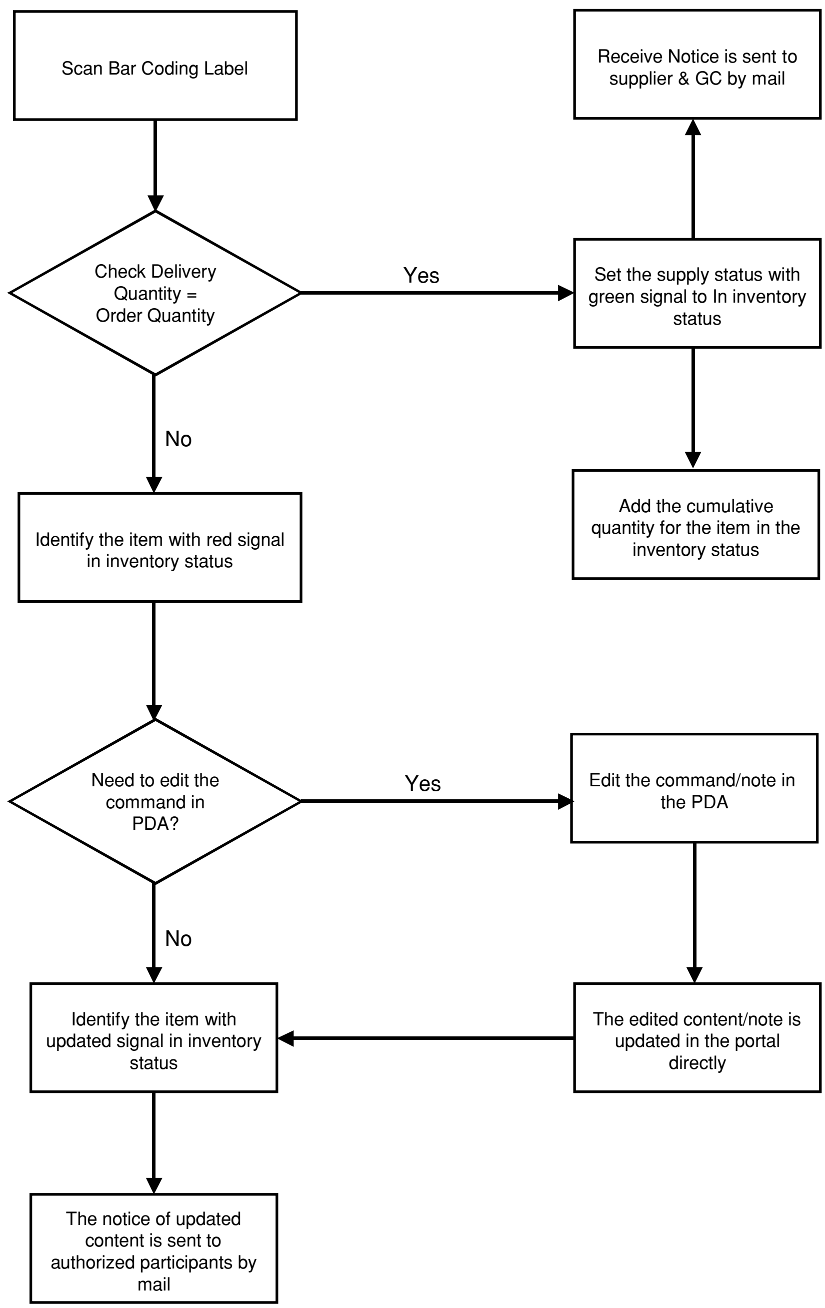

Fig. 12. Transition of the supply status during the inventory status.

components delivered in the warehouse or on the scheduled delivery list.

E-Contract and E-Specification Module: This module gives on-site engineers the ability to download specifications in advance and reference them, as if they were reading e-books on the job site during construction. It also has a "search" function that allows required information to be easily found and retrieved, saving time in the usually dynamic construction environment. On-site engineers need not carry paper contracts and can even download these contracts in advance and reference them directly from their PDAs.

E-Drawing Module: The e-drawing module supported by AutoCAD provides on-site engineers with a convenient way to work on shop drawings without carrying paper drawings. On-site engineers can download these drawings in advance and reference them on the job site during construction.

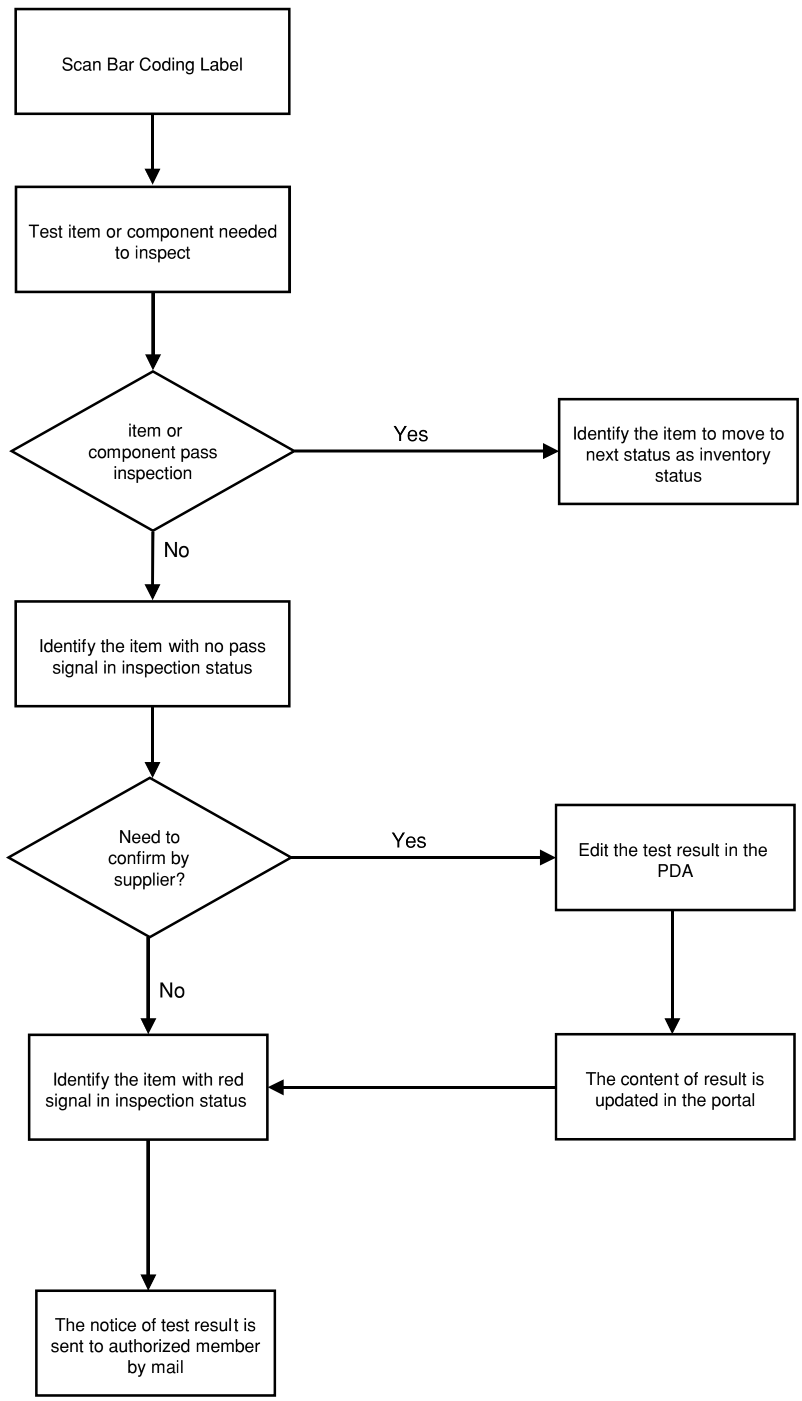

Fig. 13. Transition of the supply status during the inspection status.

5 CASE STUDY

A precast building project in Taiwan is selected to use as the basis for our case study. Full consideration of constructability in planning, design, and manufacturing phases to improve construction efficiency could significantly affect the success of precast building construction (Tatum et al., 1987). Furthermore, selection of prefabricated structural components is a major critical activity in precast building construction projects. Therefore, an efficient controlling of scheduling and plan is able to significantly reduce the construction conflicts and project delay. The structural components are prefabricated in the manufacturing plant and transported to the job site for installation. The schedules for prefabrication and transport of the structural components to the job site are developed based on the construction installation schedule. Also, the storage and management of the prefabricated components, installation sequence, schedule, and construction path planning should be well planned in advance.

In this case, the general contractor and the precast supplier try to use the M-ConSCM system to improve the project control ability. The precast component for the building project is produced in the precast manufactory. In the precast supplier phase, the supplier discusses with the general contractor to determine which component will be tracing or monitoring in the beginning. When the component is determined for project control, the bar code label regarding the component is made and the related information is setup in the system. The main description of the scenario (eight phases) is illustrated to explain the application of supply control using bar-code-enabled PDA and portals (see Figure 14). The system implementation flow diagram for the progress monitor is shown in Figure 15.

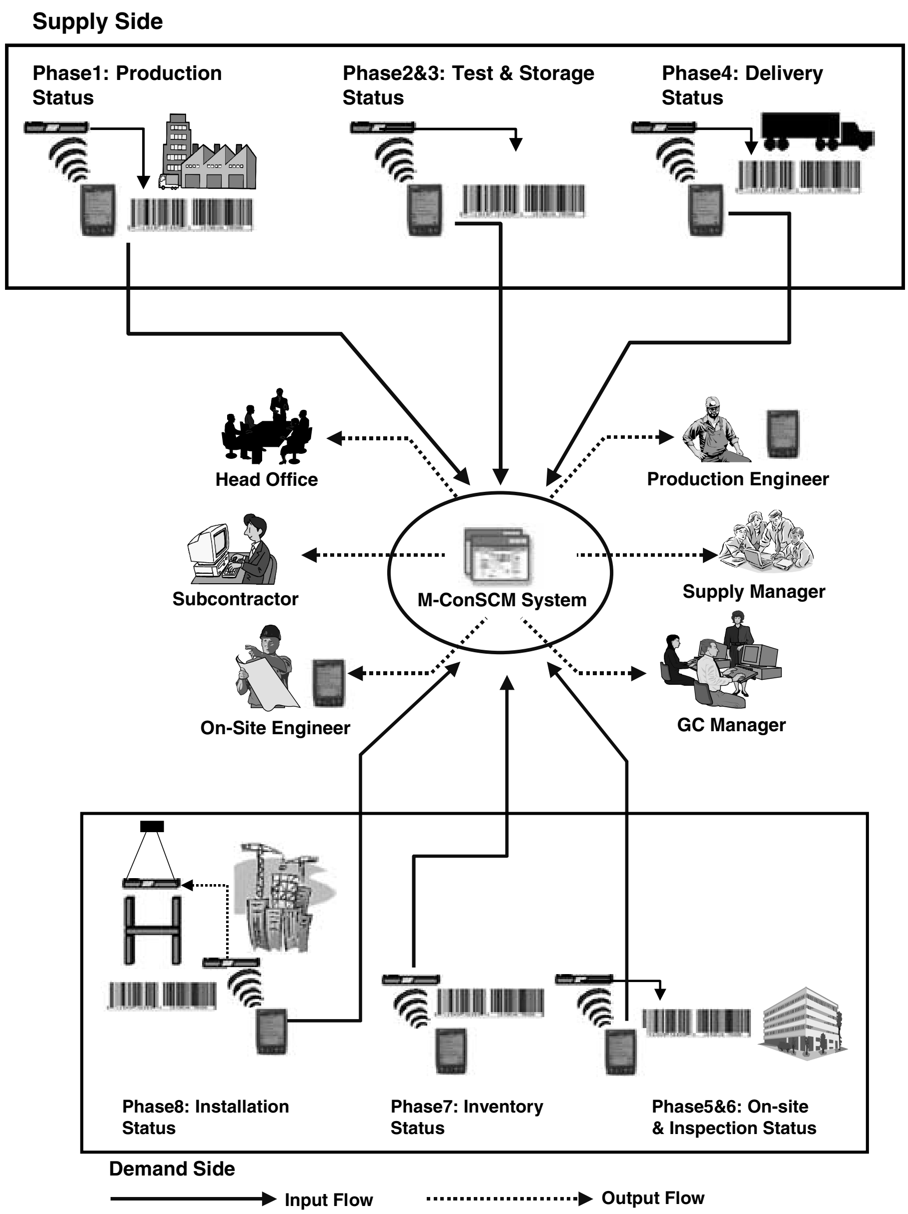

Fig. 14. Process flowchart of illustration for M-ConSCM system.

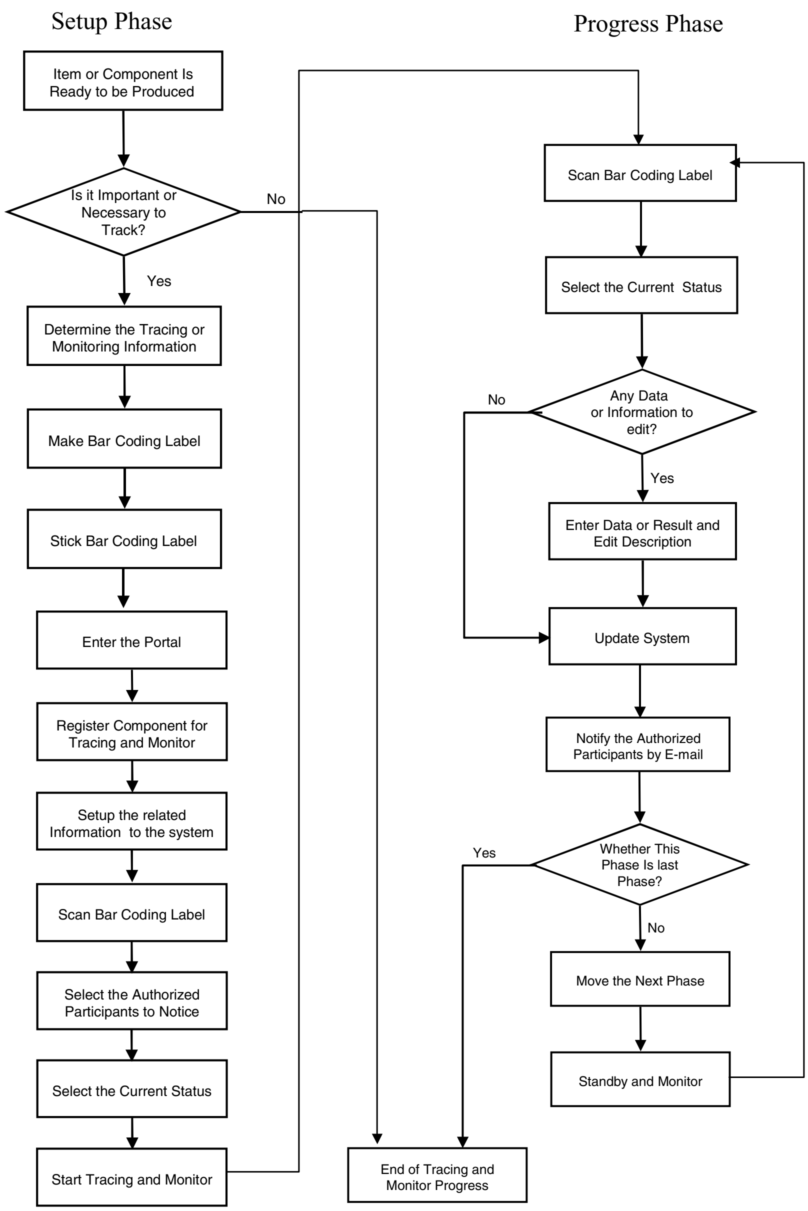

Fig. 15. The system implementation flow diagram in the progress monitor.

5.1 Production phase

In the precast supplier phase, the supplier will discuss which component will be tracing or monitoring in the beginning with the general contractor. After the component to be tracing and monitoring for project control is designed, it will be scanned with the bar code label to enter the information for the portal. Also, the general contractor can understand the updated production schedule in the portal directly.

5.2 Test and storage phase

In the test and storage phase, the precast manufactory produced the precast component and stored in inventory before they are delivered to the construction site. The engineer in the supplier side uses the PDA to scan the precast component in the inventory and enters the data and attribute concerning the precast component. The data in the PDA synchronously updated the data/information to the portal, and the manager of the general contractor may understand that the precast component has already been produced, and is under the "Inventory" status.

5.3 Delivery phase

The staff will use bar-code-enabled PDA to scan the bar code label and select the status when the precast

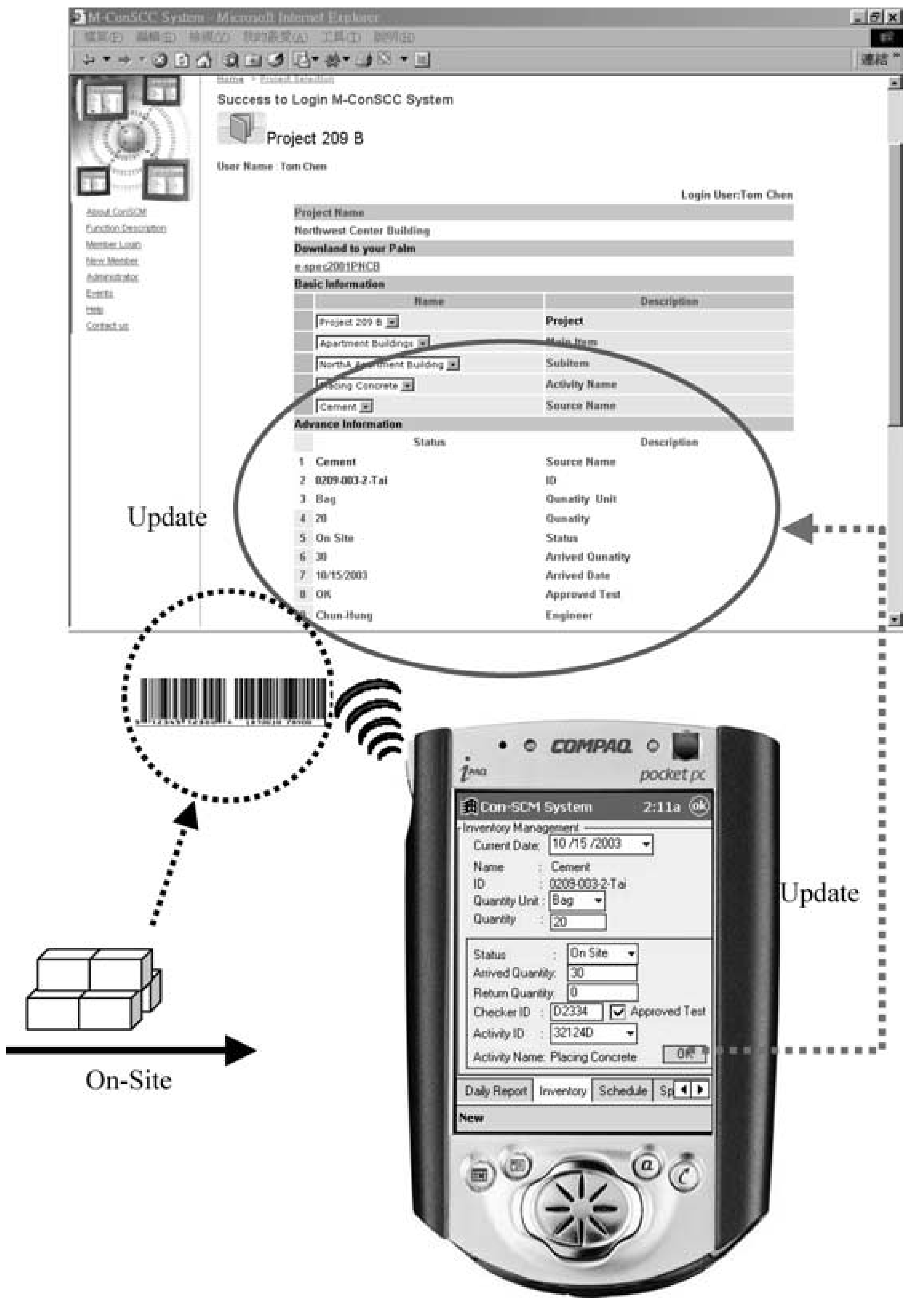

Fig. 16. The application of PDAs used in on-site phase.

component is ready to be delivered to the construction site. The data in the PDA will synchronously update the portal, and notify the general contractor to update the status of the precast component for starting delivery.

5.4 On-site inspection phase

When this component has been delivered to the site, the on-site engineers scan the bar code label to update the status (see Figure 16). PDA displays the basic information of the component and the checklist of each item. On-site engineers enter the result and edit the description in the PDA and update the updated information to the portal. In the meantime, the system will automatically alert the project manager in the head office to see the portal and check the updated information. Also, the supplier may check from the portal the amount of components delivered to the construction site.

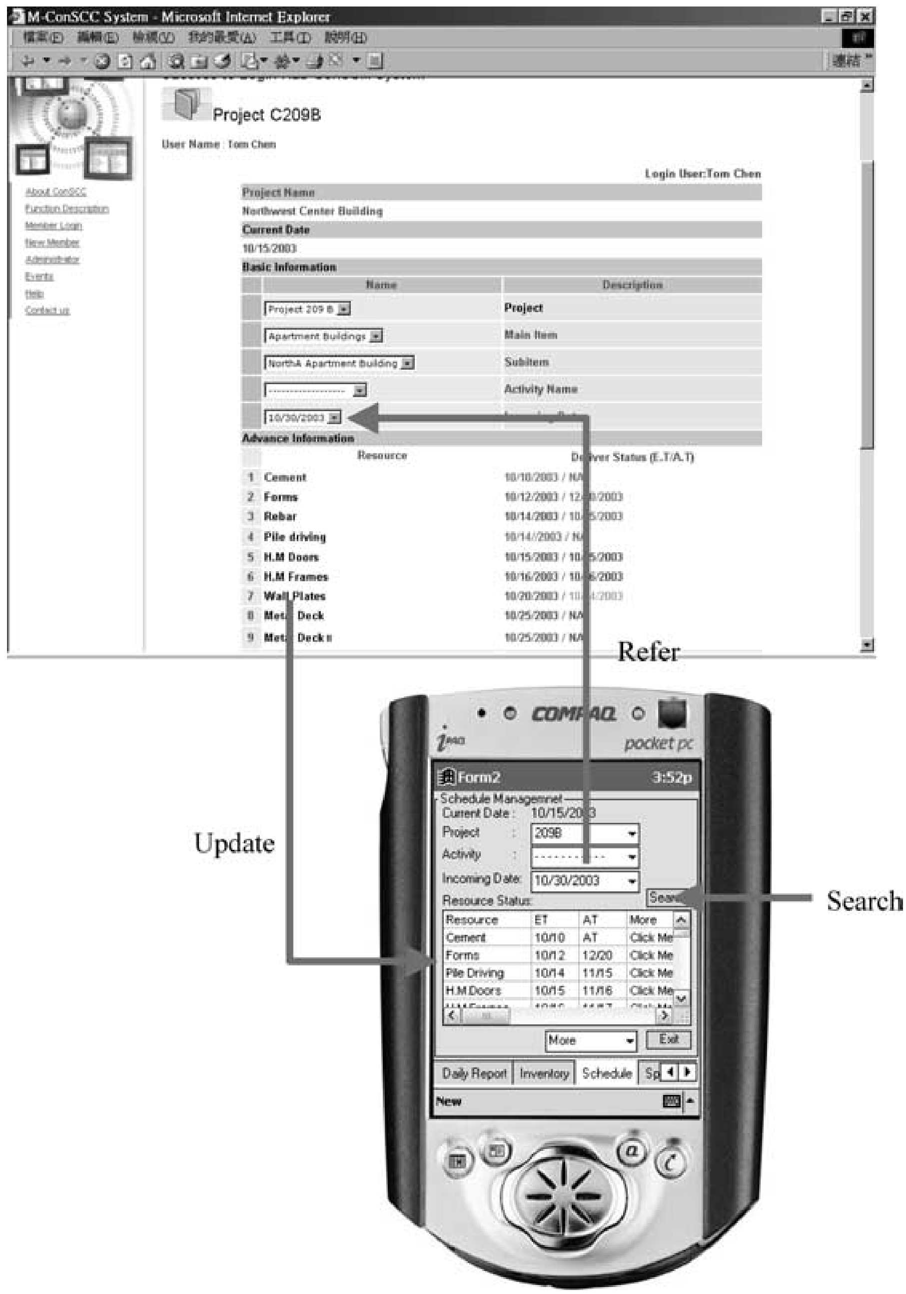

Fig. 17. The application of PDAs used in the inventory phase.

5.5 Inventory phase

After the component is delivered in the construction site, the field engineer needs to check the component for quantity and quality, then enter the result in the PDA. Finally, the tracking process for the component will update the status to pass the test synchronously in the portal, and let the manager of the general contractor or the authorized suppliers check the process. Furthermore, the on-site engineer utilizes the web browser (IE6) on the PDA directly to check the late-delivery items for inventory, according to the special day and project (see Figure 17).

5.6 Installation phase

Before the installation, the engineer checks the installation locations and marks the problems in the PDA directly (see Figure 18). The result/problem is updated in the M-ConSCM system portal. The project manager and

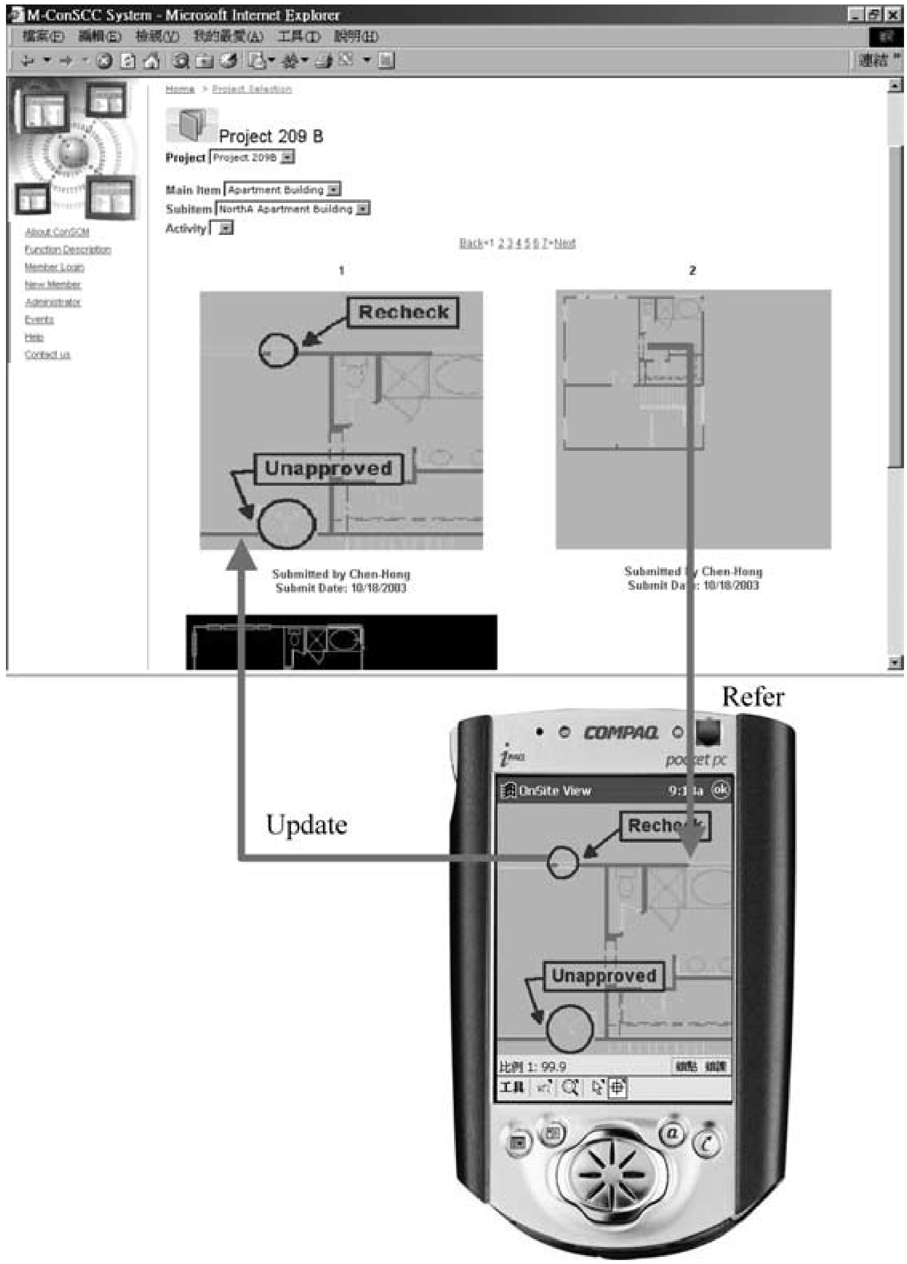

Fig. 18. The application of PDAs used in the installation phase.

subcontractor can understand the installation situation quickly and directly from the portal. When the component is ready to be installed after the testing and confirmation process, its bar code label needs to be scanned again by the on-site engineer to update the information for the installation phase. Also, the information will be updated and announced synchronously in the portal. For the contractor and suppliers, they can gain information and understanding of real-time situations and advance a plan concerning their tasks.

6 CONCLUSIONS

This article presents a web-based portal system that incorporates wireless technology and mobile devices to improve the efficiency and effectiveness of data acquisition on site and information sharing between participants to assist the managers to control and monitor the construction supply chain delivery progress. The M-ConSCM system not only improves the data acquisition on site efficiency by using automated bar-code-enabled

PDA, but also provides a monitor to control the construction progress. On the client side, on-site engineers use PDAs to overcome time and space constraints, enabling them to read and record/edit all necessary or important information. On the server side, the M-ConSCM system offers a hub for the information and control center to provide suppliers and subcontractors real-time updated project-related information and to monitor the construction progress. In the case study, the application of the M-ConSCM system assists in improving operation progress monitoring for precast building construction (real-case application for office buildings in the Nankang Software Park of Taiwan, Taipei). The integration of real-time production and delivery information from precast supplier makes it easy for the GC manager to monitor and control the whole construction progress. Furthermore, the precast supplier may update the erection progress to reschedule the precast components production and assessment in real time. Real-time feedback regarding the status of progress on-site is provided to the fabricator off-site, so process steps can be resequenced opportunistically. In comparison with the current methods, all the information/data communication in the site can be improved by using automated bar-code-enabled PDAs and the information sharing among participants and is made quicker and more efficient through the portal technology.

7 SUGGESTIONS

Based on the findings of the case study, it appears that mobile devices are useful tools as they are related to the construction site operation progress. As the next step in the implementation process for further research, some suggestions are provided as follows:

1. It is very important to understand what information is needed to be shared among project participants because all content or information shared will differ from project to project. Therefore, it is necessary for participants to have several meetings and discussions about information sharing before modifying and developing the system.
2. The general contractor needs to take an active role in implementing the system on construction projects because most participants (suppliers) may be unable or unwilling to cover the additional costs involved due to their budget constraints.
3. Mobile devices should include durable functions for protection against physical shock, rain, moisture, and dust, if on-site engineers have to use them in construction sites.
4. Easy user interface by pen-touch is convenient and suitable for on-site construction engineers because most of them may input data to the PDA with gloves on their hands.
5. Speed of operation and long-life batteries play an important role in the use of the mobile device in construction sites. Furthermore, the capability of a member card influences the use time when on-site engineers check drawings and pictures on the mobile device.
6. Bar code labels may be easily damaged during transportation, and items of construction are cumbersome to scan for on-site engineers. Use of bar code labels handbook should be suggested for easy scan. This handbook contains all bar code labels for all kinds of the construction components/materials traced or monitored by the system.

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