SUPPLY CHAIN MANAGEMENT SYSTEM FOR CURTAIN WALLS USING RFID TECHNOLOGY

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ABSTRACT : This research presents a collaborative supply chain management system for curtain walls using Radio Frequency IDentification (RFID) to track the product and information flow among participants in high-rise building construction projects. This resarch developed a process model and a strategy for effective utilization of RFID technology through the curtain wall life-cycle. Then an information management system was developed to support the supply chain management of curtain walls with incorporating RFID into curtain wall products flow throughout the life-cycle. The system has been tested for validation and verification in a real world project.

Key words : RFID, Ubiquitous Computing, Progress Management, Information System, Supply Chain Management

1. INTRODUCTION

Curtain walls (C/Ws) are the most widely used exterior wall systems for high-rise buildings in Korea. They occupy a relatively high portion of total construction cost, about 10-15%, and their activities are typically on the critical path of the project schedule. Furthermore, the life-cycle process of curtain walls requires effective and efficient coordination and cooperation among tens of companies, including the owner, architect firm, curtain wall consultant, manufacturer, contractor, and subcontractors, etc.

To ensure the quality of curtain wall construction, the management scope of construction managers should be expanded to the whole curtain wall supply chain which consists of manufacturing curtain walls, procurement management of curtain wall units and their accessories, installation at the site, and coordination between manufacturer and constructor. Since most construction projects adapt unit-type curtain walls rather than stick or semi-unit type curtain walls, in which most works are done at the job site, effective and efficient coordination and cooperation among participants become even more critical.

Meanwhile RFID technology has emerged with potential for application in the construction industry, replacing bar codes. A workshop held by the Construction Industry Institute showed that RFID could be feasible and beneficial in many areas including engineering/design, material management, maintenance, and field operations [1]. RFID, contactless reading technology, includes tags that allow sensing of the project's progress even in harsh conditions where bar codes cannot survive. Application of RFID could automate the data collection process not only for construction progress, but also for project progress management throughout the supply chain, including design, ordering, delivery, receiving, and installation of material and products. This would make progress management more proactive and predictable and enable real-time progress management.

Therefore, the objective of this research is to improve efficiency and effectiveness of the curtain wall life-cycle process by developing a collaborative supply chain management system by using RFID technology. This research has developed a business process to manage information and curtain wall product flow using information technology and

Radio Frequency IDentification (RFID) among the participants.

2. SUPPLY CHAIN PROCESS OF CURTAIN WALL

A life-cycle process of C/Ws was analyzed on the basis of material/product and information flow. Based on the characteristics of each phase in the life-cycle, the process can be divided into four phases at the top level: design, manufacturing, on-site construction, and maintenance.

The design phase is sub-divided into architectural design and C/W design activities. Information created in the design phase includes facade design, structural design, criteria setup for required performance, material, fastener and joint details, and many other aspects that cover both architectural and engineering designs.

The manufacturing phase consists of two sub-phases: supplying materials and parts, and manufacturing C/Ws. The manufacturing C/Ws phase is, in turn, sub-divided into sub-processes, such as pressing, painting, cutting, assembling, glazing, packing, inspection, and delivery.

The construction phase, when C/Ws are installed at the site, is sub-divided into hoisting and installation processes. Information generated in the hoisting process includes: delivery plan of C/Ws, packing and handling, transportation to and inside the site, stockyard and protection plans, labor and equipment plans, etc. Installation information includes as-built data of the C/W, such as unit quantity to be installed, locations in stockyard, inspection results, etc., according to the installation schedule.

Through the analysis and interviews with practitioners involved in the curtain wall process, the problems and waste encountered in the supply chain of the C/W life-cycle process are caused fairly by information loss and redundancy, difficulties in information sharing and communication, and lack of collaboration and coordination among actors. Therefore it is necessary to build an information framework to support collaboration among all the actors involved in the C/W life-cycle based on the SCM concept. This would be the most effective way for reengineering the current process since it can reduce lead time, improve service and quality, and reduce cost over the life-cycle.

The information framework would also have to support the integration and share of information among the actors in the supply chain, spanning from the design to the operation and maintenance phases.

Therefore this research has focused on the followings to improve efficiency and effectiveness of the curtain wall life-cycle process: 1) collaboration environment for the supply chain management through the C/W life-cycle, 2) share of C/W information, and 3) product and information flow management through the use of RFID in the manufacturing and on-site construction processes

3. CONSIDERATIONS FOR CHOOSING RFID TECHNOLOGY

Radio Frequency IDentification (RFID), one of the automatic identification and data capture technologies, is being increasingly adapted to manage material and product flow throughout the supply chain process in various industries. RFID is an electronic labeling and data-collection system to identify and track items using radio frequency (RF) signals. An RFID system consists of three basic components: 1) tag, 2) antenna, and 3) reader. A tag, also called a transponder, is classified as active or passive, and it has read-write or read-only capability (Finkenzeller 2002). RFID is considered to be the next generation technology of bar codes, which have been limited in their utilization due to problems, such as ease of damage, low readability under direct sunlight, and lack of durability in harsh construction conditions (Jaselskis 2003). Recently, researchers and practitioners in the construction industry have shown their interest in considering RFID as a feasible technology that can substitute for bar codes by funding research projects. Some such projects included: identification of possible applications of RFID in construction (Jaselskis 1995; CII 2000); verification of process efficiency of RFID application through a pilot test (Navon 2002; Umetani 2004; Jaselskis 2003); and application strategy of RFID in construction (Jaselskis 2003).

However, existing research projects regarding RFID applications in construction have mainly focused on the feasibility of RFID technology itself rather than the characteristics and the life-cycle process of a product or material where RFID was applied. Therefore, referring to the decision-making flow chart developed by Jaselskis (2003), this research has further developed the considerations to support requirements in the supply chain of curtain walls in a more practical way. The considerations have been derived through interviews, visits, and workshops with researchers and practitioners in the construction and RFID industries, followed by field testing and prototype system development. As a result, they can be categorized into three aspects: 1) technology availability, 2) domain applicability, and 3) information management strategy. Each of these categories is explained below.

First, the technology availability represents considerations on the type of data transmitted by RFID tags, the frequency allowed at the project location, a suitable reading method for tags, and the economic feasibility of RFID technology at the time of application. In Korea, while passive tags are easily available on the market, active tags need to be imported and their prices are currently at least ten times higher than that of passive ones. Regarding frequency, 125 KHz, 13.56 MHz, and 900 MHz RFID technologies are available, and 2.4GHz RFID technology will be available soon but are not yet approved for use. Reading method for tags can be considered in two ways, one is to build an antenna and reader at a fixed location and

the other is to use a PDA module containing an RFID reader. An additional consideration is that the technology should be applied at an affordable price.

Second, the domain applicability represents whether the RFID technology is applicable and how it can be applied in the target domain to the aspects of technology, economy, and business process. First of all, it is necessary to determine what RFID technology would be applicable to a given application domain. For example, it is practically impossible at this time to build a reader and antenna at the gate to detect the product flow using RFID sensing because of the high cost of installation and insufficient reading distance between the antenna and incoming products. Instead, it is more practical and feasible for managers to use PDA modules with RFID readers to read tags attached to products at the site. In addition, different RFID tag types could be chosen depending on the tracking target. Furthermore, the current business process needs to be analyzed and reengineered to take more efficient and effective advantage of the RFID technology.

The third category, the information management strategy, represents the management purpose in RFID application, the management steps in the process of the target domain, and how RFID tags are assigned to products in order to meet the management purpose. For example, there can be various management purposes in RFID application, such as tracking supply chain of products, inventory management, and manpower management. When the RFID technology is applied to supply chain management between manufacturer and general contractor, it is also important what and how many steps in the supply chain process need to be managed through the RFID technology, since the number of management steps using RFID directly affects the cost of RFID application. Based on the management purpose and requirements, tag assignment units are determined. For example, for ready mix concrete operations, an RFID tag is assigned to an invoice, whereas it can be assigned to a product unit for the curtain wall case.

These three categories of considerations are not independent but closely interrelated with each other. Therefore, when an RFID-based process is designed, all these considerations should evaluated and satisfied for a given application domain. In this research, based on these three factors, an RFID application strategy and process model for the supply chain management of curtain walls in high-rise building construction projects were developed, and the details are described in the next section.

4. RFID APPLICATION STRATEGY FOR SUPPLY CHAIN MANAGEMENT OF CURTAIN WALLS

Based on the three categories of consideration described in the previous section and through interviews and workshops with practitioners involved in the supply chain of curtain walls, the application strategy has been developed as follows:

(1) Passive type 13.56 MHz RFID technology has been chosen. 125 KHz, 13.56 MHz, and 915 MHz RFID technologies are available at this time (technological availability); and these technologies were tested for reading distance and conditions with curtain wall units. Based on results of the reading test, 13.56 MHz was selected for tracking curtain wall units (domain applicability). RFID tags are assigned to each curtain wall unit as soon as the unit passes quality inspection in the manufacturing phase. In addition, for a more efficient shipping and receiving process, an RFID tag is also attached to each pallet, which is a carrying unit for curtain walls. Typically, each pallet carries 2-3 curtain wall units from the factory to the construction site and then to the location where the units are to be installed (domain applicability and information management strategy).

(2) PDA modules with RFID readers have been adopted. Regarding technological availability, two options are available: antenna and reader at a fixed location, and PDA with RFID reader. However, it is practically impossible to read RFID tags with an RFID reader installed at the gate, since it is not possible to read tags through the aluminum frame curtain wall units (domain applicability). Curtain wall units need intensive quality inspection and management, and managers should require that quality inspections throughout the supply chain process are associated with the RFID-based process. Since the quality of curtain wall units are inspected by various methods and participants, it is more efficient and effective to use the PDA module with RFID reader option, since quality inspection can also be performed by using PDAs (information management strategy).

(3) Card type RFID tags have been chosen. Various kinds of tags, such as stickers, bands, cards, and many other customized tags are available (technological availability). However, using customized tags would increase the application cost dramatically at this time, since the number of curtain wall units is not large enough to get custom RFID tags at a low price. Therefore, among the standard types of the RFID tags, the card type was chosen based on the reader test results and their applicability to the curtain wall process. Tags need to be attached to glass or aluminum parts of curtain wall units and to the side of pallets. Since sticker type tags can not be read when they are attached to metal components, card type RFID tags with ferrite coatings on their backsides have been developed (domain applicability).

5. RFID-BASED SUPPLY CHAIN MANAGEMENT OF CURTAIN WALLS

5.1 RFID-based process for Curtain Walls

The RFID–based supply chain management (RFID-SCM) process was developed for 3 months from February to May of 2005. Many interviews, visits, and workshops with

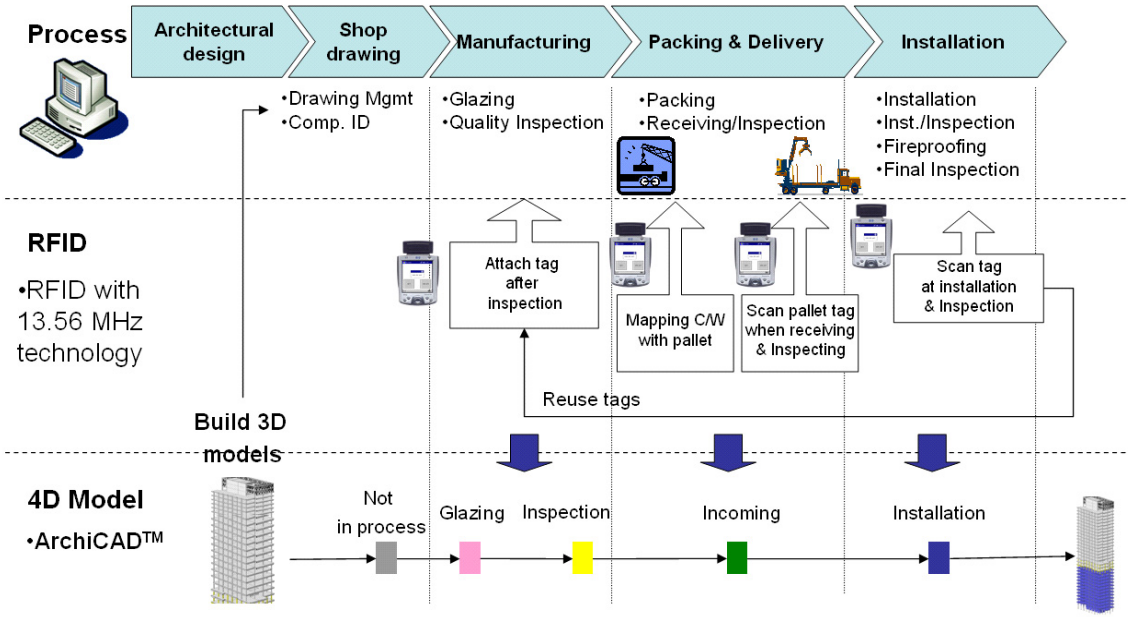

Fig. 1. RFID process for Curtain Walls

practitioners at the manufacturing and construction sites of a pilot project have been conducted. As a result, the RFID-SCM process for curtain walls was developed as shown in Fig. 1. The pilot project, located in a suburb of Seoul, Korea, has two 42-story buildings that have about 12,000 curtain wall units, and it has been selected for the pilot test to verify and validate the RFID application strategy and its process.

For the given project, depicted in Fig. 1, the process begins with generating component identification numbers (IDs), since components are managed on a unit basis through the life-cycle. During manufacturing, progress information is managed in two steps: 1) when glazing of a curtain wall unit is completed, and 2) when the production of the unit is completed and passes the quality inspection. RFID tags are assigned to curtain wall units that have passed the quality inspection. The progress information is also shared among the manufacturer, the installation contractor, and the general contractor through the Internet. Since 2-3 units of curtain walls are carried by a pallet, RFID tags are also assigned to each pallet to keep track of the product flow on a pallet basis from shipping to installation at the construction site. When a curtain wall unit is loaded on a pallet in the factory, the manager maps the RFID tag of the loaded unit with the tag of the pallet using a PDA.

When the pallet is delivered to the construction site, the general contactor scans the tag on the pallet to determine whether the right components were delivered to the site. In addition, through the quality inspection functions on the PDA module, the checklist for quality inspection is filled out for the incoming curtain wall units. These steps change the status of the units to "delivered." Inspected units are transported to the place where they are to be installed. After the subcontractor installs the curtain wall units, the tags of the units are scanned using a PDA to change their status to "installed." Tags on the curtain units are removed when the general contractor confirms the installation of each curtain wall unit, and the tags are sent back to the manufacturer for reuse with new curtain wall units.

5.2 RFID-based Supply Chain Management System for Curtain Walls

An RFID-based supply chain management system for curtain walls (RFID-SCMS) has been developed based on the process model described above. The system architecture of RFID-SCMS is shown in Fig. 2. RFID-SCMS consists of four components: 1) a Web-based system to support the information flow and collaboration among project participants; 2) an RFID module that automates the management of product flow through the supply chain; 3) a PDA-based quality management system that supports quality inspection through the supply chain; and 4) visualization of curtain wall progress in a 3D model reflecting on each unit's status through the supply chain.

The system was developed not only for verification and validation of an RFID-based process for curtain walls but also for use in a real world project. Since RFID-SCMS is Web-based, relevant participants can access and share curtain wall progress information through the designated uniform resource locator (URL). The progress information is captured from the manufacturing phase, when glazing of a curtain wall unit is

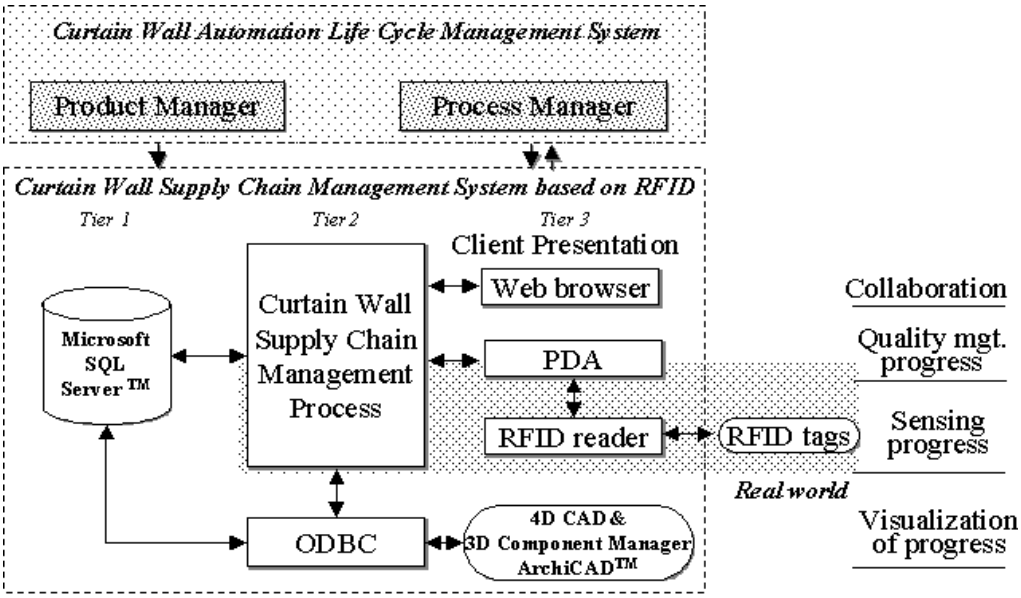

Fig. 3. System Architecture

completed, until to the installation of the curtain wall unit is completed and confirmed by the general contractor.

PDA modules with RFID readers enable an RFID tag to be assigned to a curtain wall unit and the tag to be scanned to change the progress of the curtain wall unit. The PDA module also supports checklists to be filled out for quality inspection at both the manufacturing and construction sites. Currently, a total of four PDA modules were deployed at the factory and construction sites, with two modules at each location. At the manufacturing site, the quality inspector and the packing manager have the modules, while the installation subcontractor and general contractor have one each at the construction site. The PDA modules are synchronized with RFID-SCMS on a daily basis or whenever necessary, and the up-to-date progress information is also fed to 3D models created in ArchiCAD™ through open database connectivity (ODBC). 3D models are presented in different colors depending on their progress status (refer to Fig. 3 and 4).

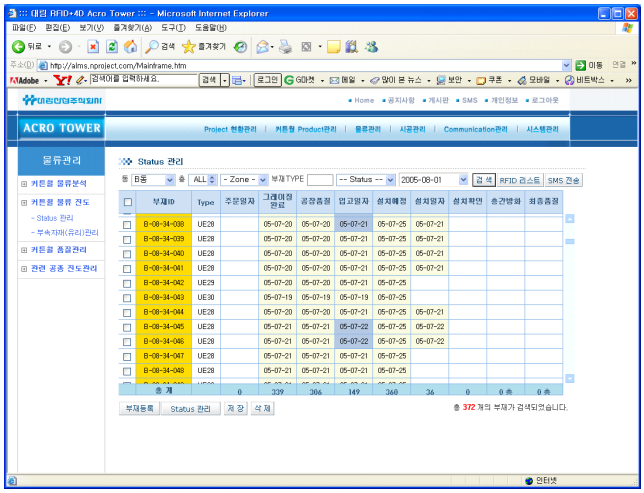

Fig. 2. Status View in RFID-SCMS

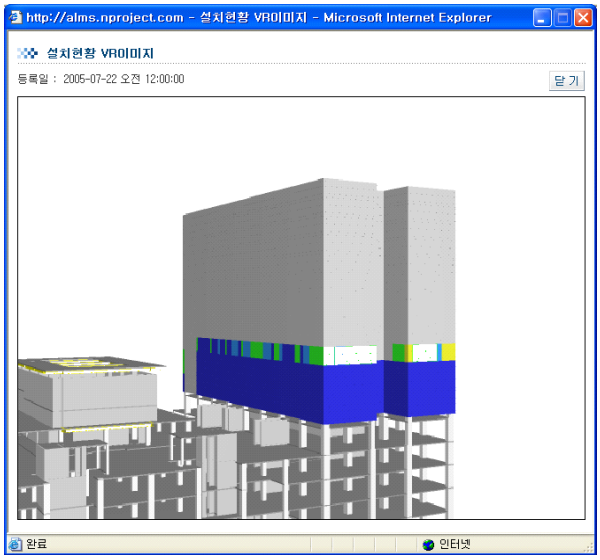

Fig. 4. Virtaul Reality based on Progress in RFID-SCMS

6. CONCLUSIONS

This research identified three categories of considerations that should be taken into account to determine the most effective and efficient RFID technology for the supply chain management of curtain walls in the construction industry. These categories are 1) technology availability, 2) domain applicability, and 3) information management strategy. Based on these considerations, characteristics and business processes of curtain walls, an effective and efficient RFID application strategy has been developed in this research. The RFID strategy includes the adoption of reusable card type of RFID tags attached to curtain wall units and pallets, and the use of PDA type readers to keep track of progress information. Based on the strategy, the RFID-based supply chain management system for curtain walls (RFID-SCMS) was developed for use in a real world construction project. The system has been implemented successfully since the middle of July, 2005, and feedbacks are collected for refinement of RFID-SCMS. At the time of presentation of this paper, the results of the real world application and lessons learned will be shared.

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